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Biskeborn

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(54) **MULTI-BAND MULTICHANNEL MAGNETIC RECORDING HEAD**

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This patent is subject to a terminal disclaimer.

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(51) **Int. Cl.**

G11B 5/008	(2006.01)
G11B 5/78	(2006.01)
G11B 5/02	(2006.01)

(52) **U.S. Cl.**

CPC ***G11B 5/00813*** (2013.01); ***G11B 5/02*** (2013.01); ***G11B 5/78*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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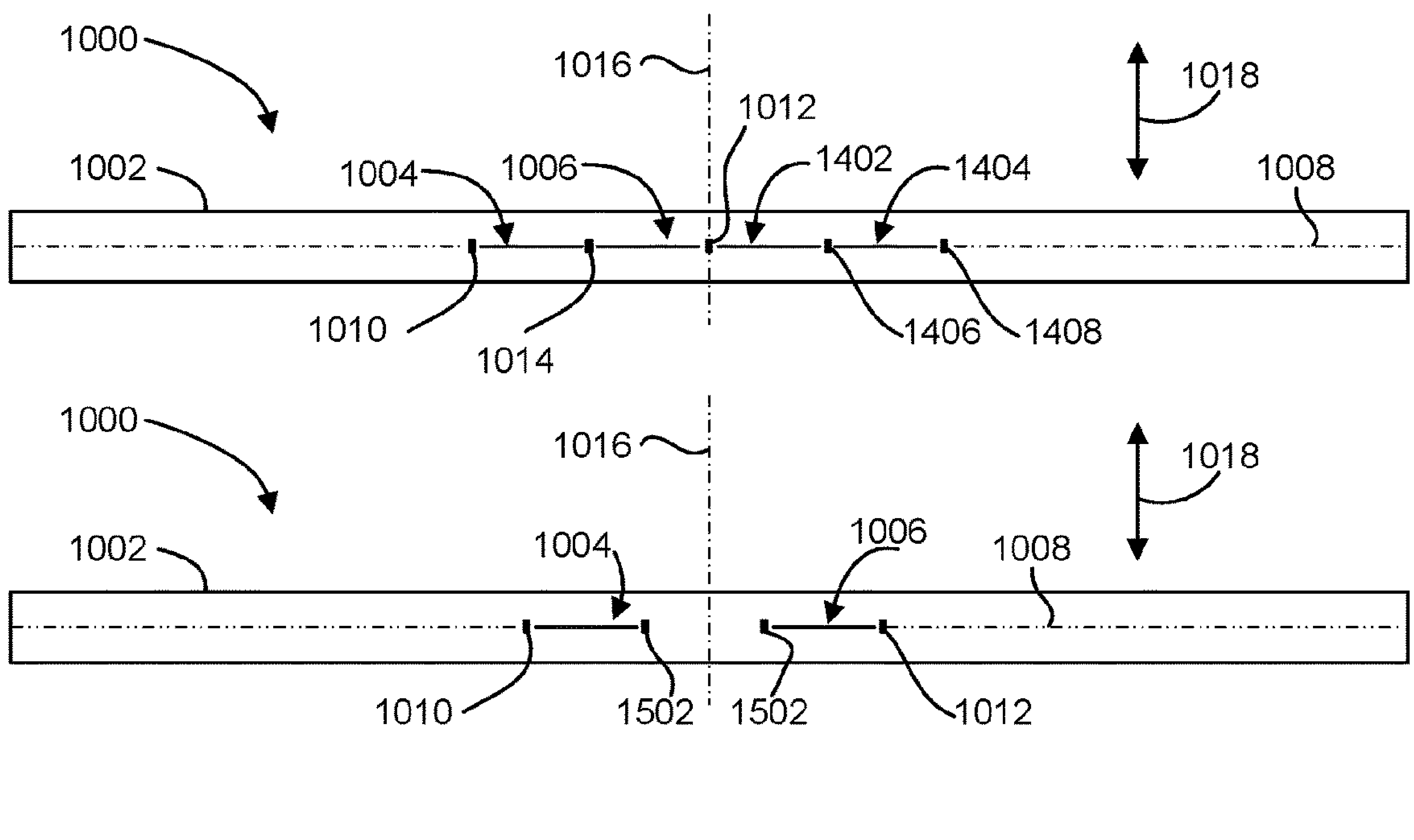
(57) **ABSTRACT**

An apparatus, according to one approach, includes two arrays of data transducers on a module, the two arrays being aligned along a common axis extending between distal ends of the module. Outer servo readers are positioned toward outer ends of the two arrays. An inner servo reader is positioned between the two arrays. The servo readers are positioned to each reside above a unique servo track on a magnetic recording tape. A method according to one approach includes passing a magnetic recording tape having a plurality of data bands over a module as described above. Data is simultaneously transduced on the two data bands using the data transducers. Advantageously, the number of simultaneously-usable channels on the module is dramatically increased, thereby also dramatically increasing the data rate per unit of tape speed, while backward compatibility may be preserved.

15 Claims, 15 Drawing Sheets



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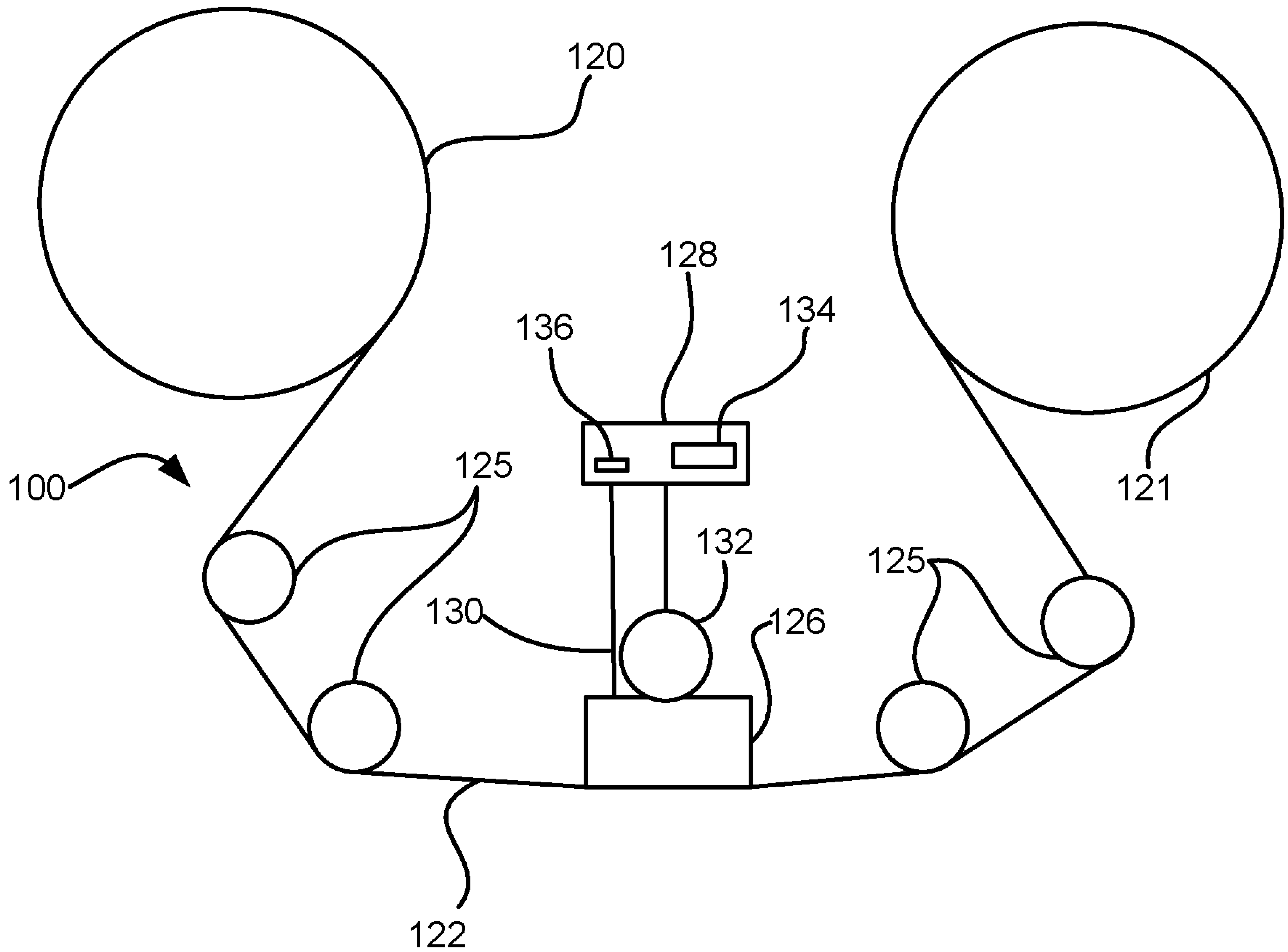
120
128
136
134
100
125
121
132
130
125
126
122

FIG. 1A

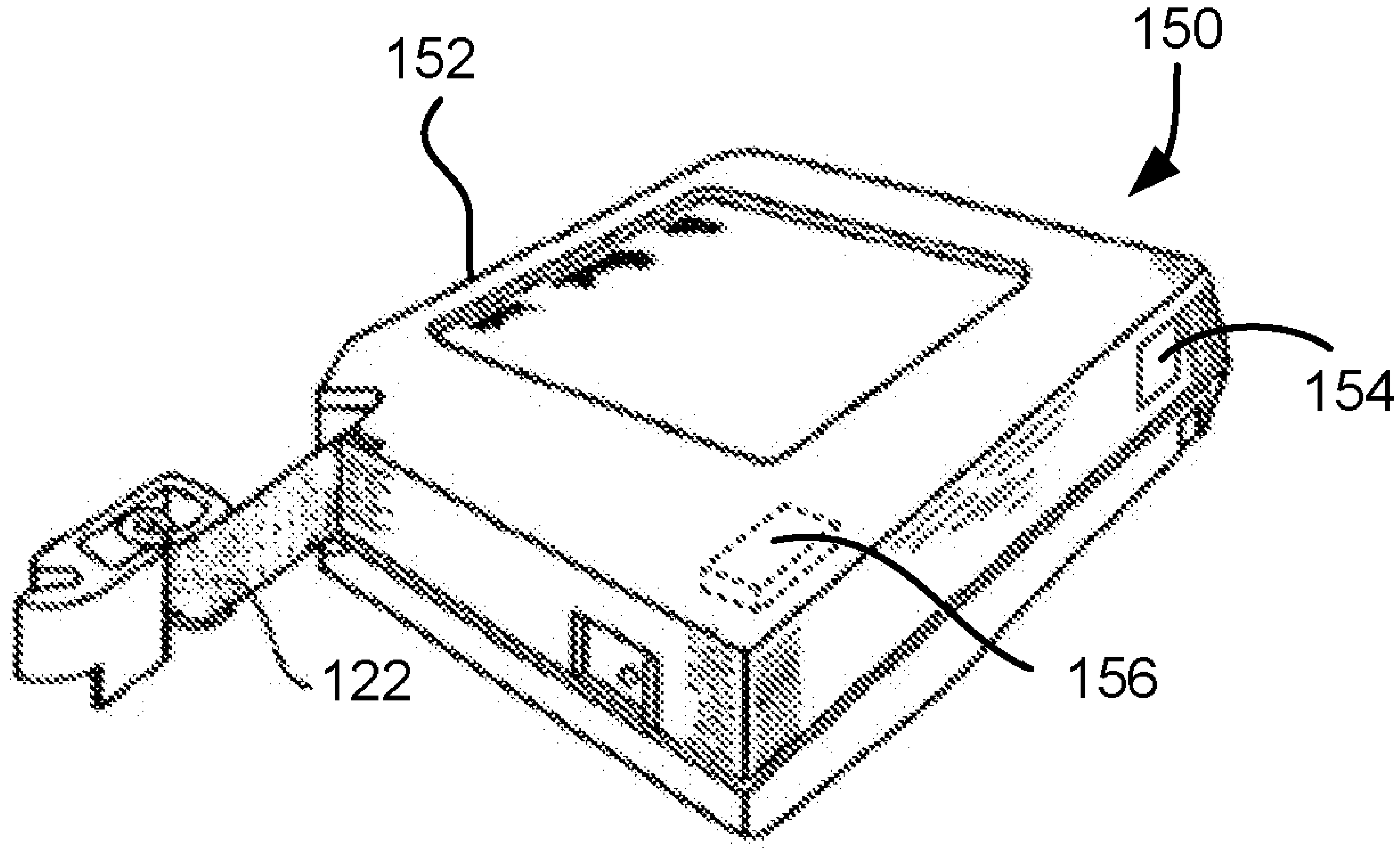
152
150
154
122
156

FIG. 1B

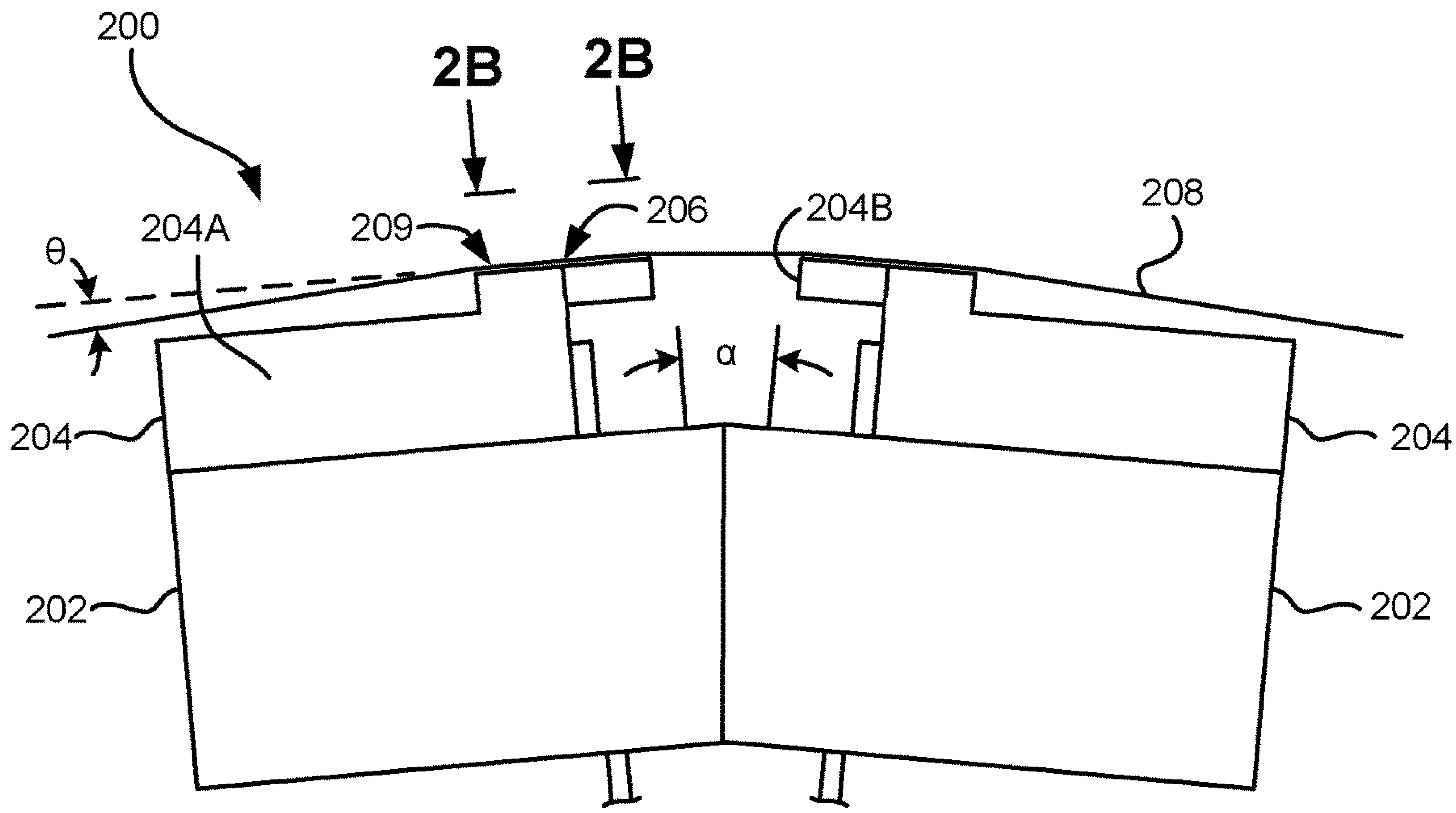
200
2B
2B
206
204B
208
209
204A
θ
α
204
204
202
202

FIG. 2A

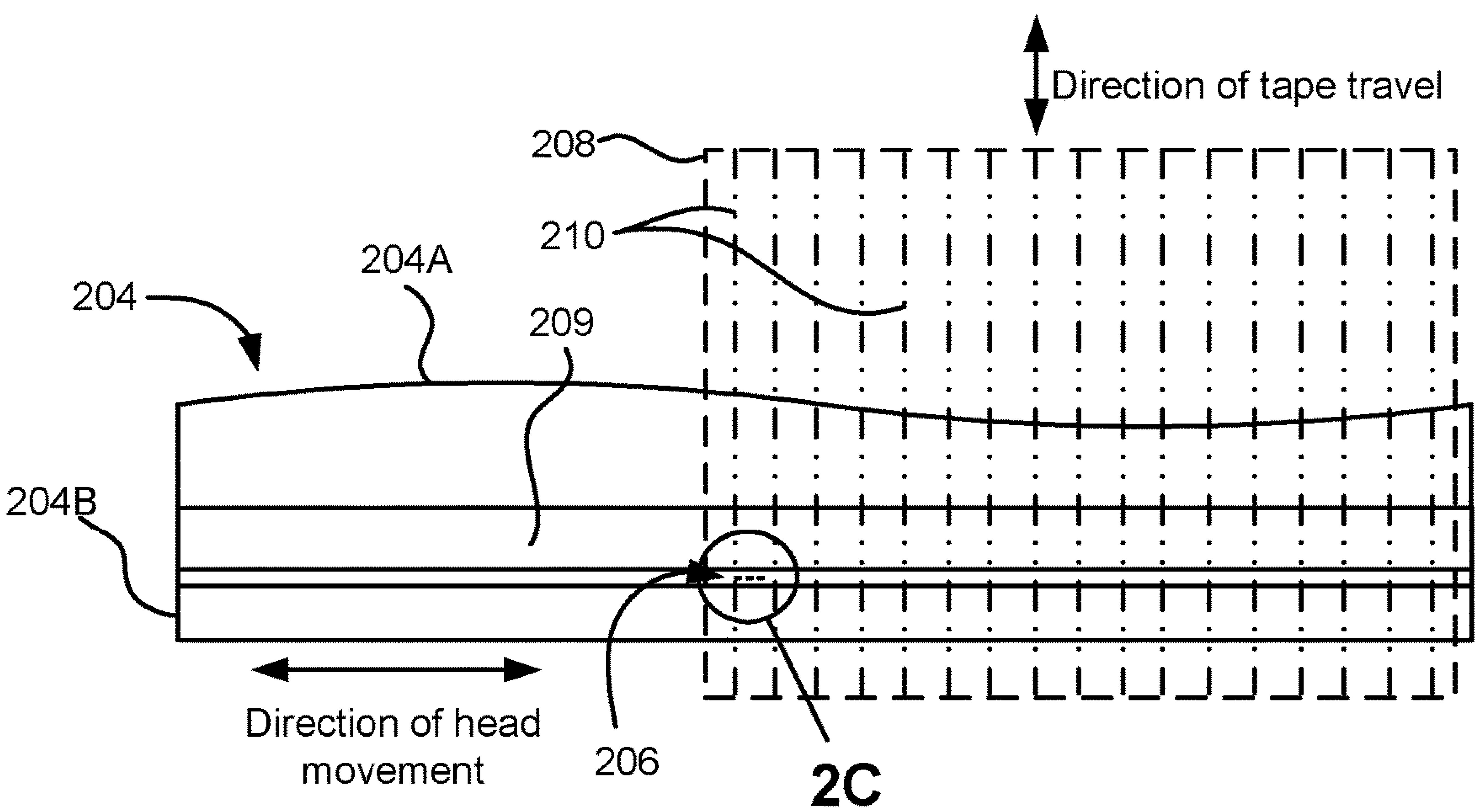
Direction of tape travel
208
210
204A
204
209
204B
Direction of head movement
206
2C

FIG. 2B

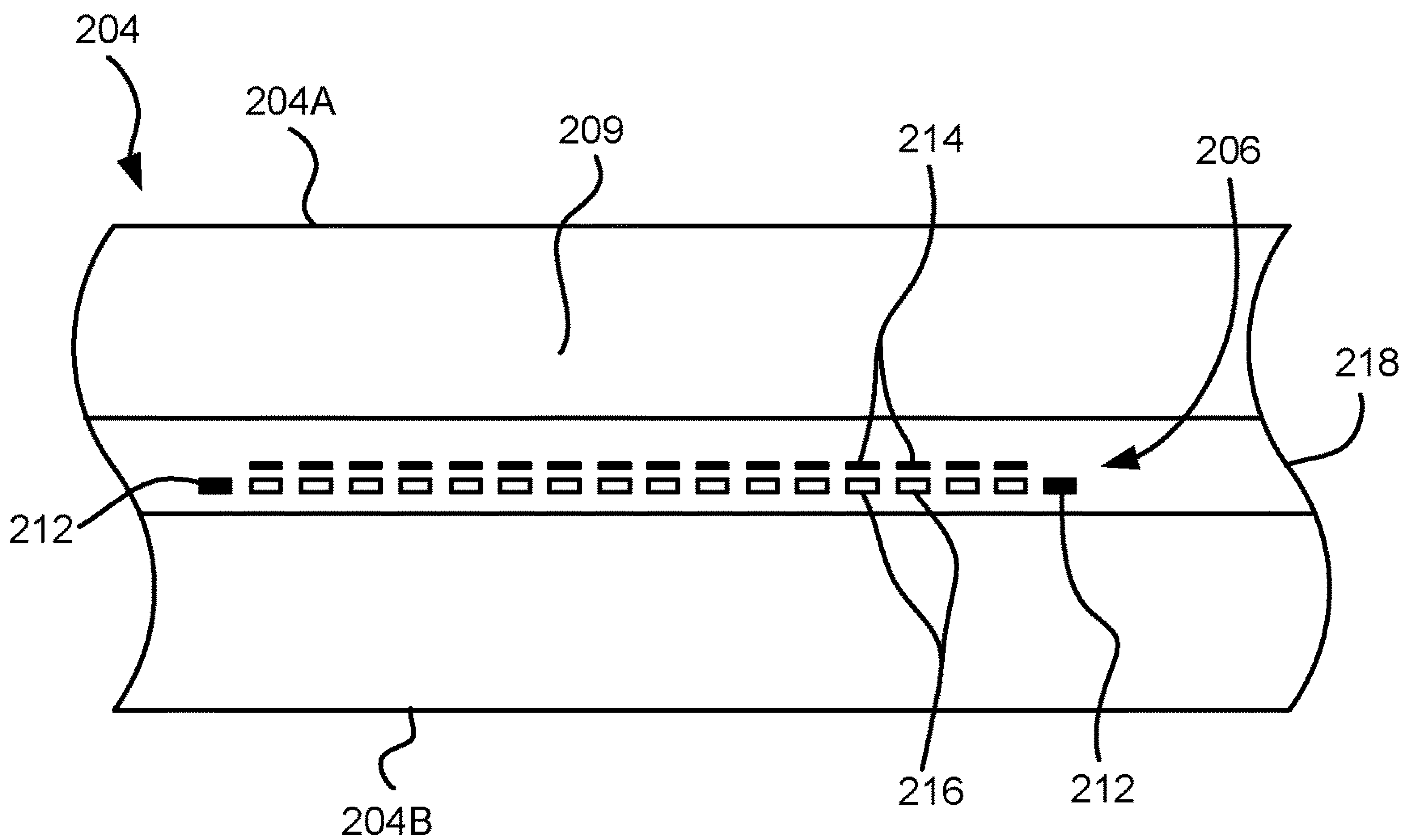
204
204A
209
214
206
218
212
216
212
204B

FIG. 2C

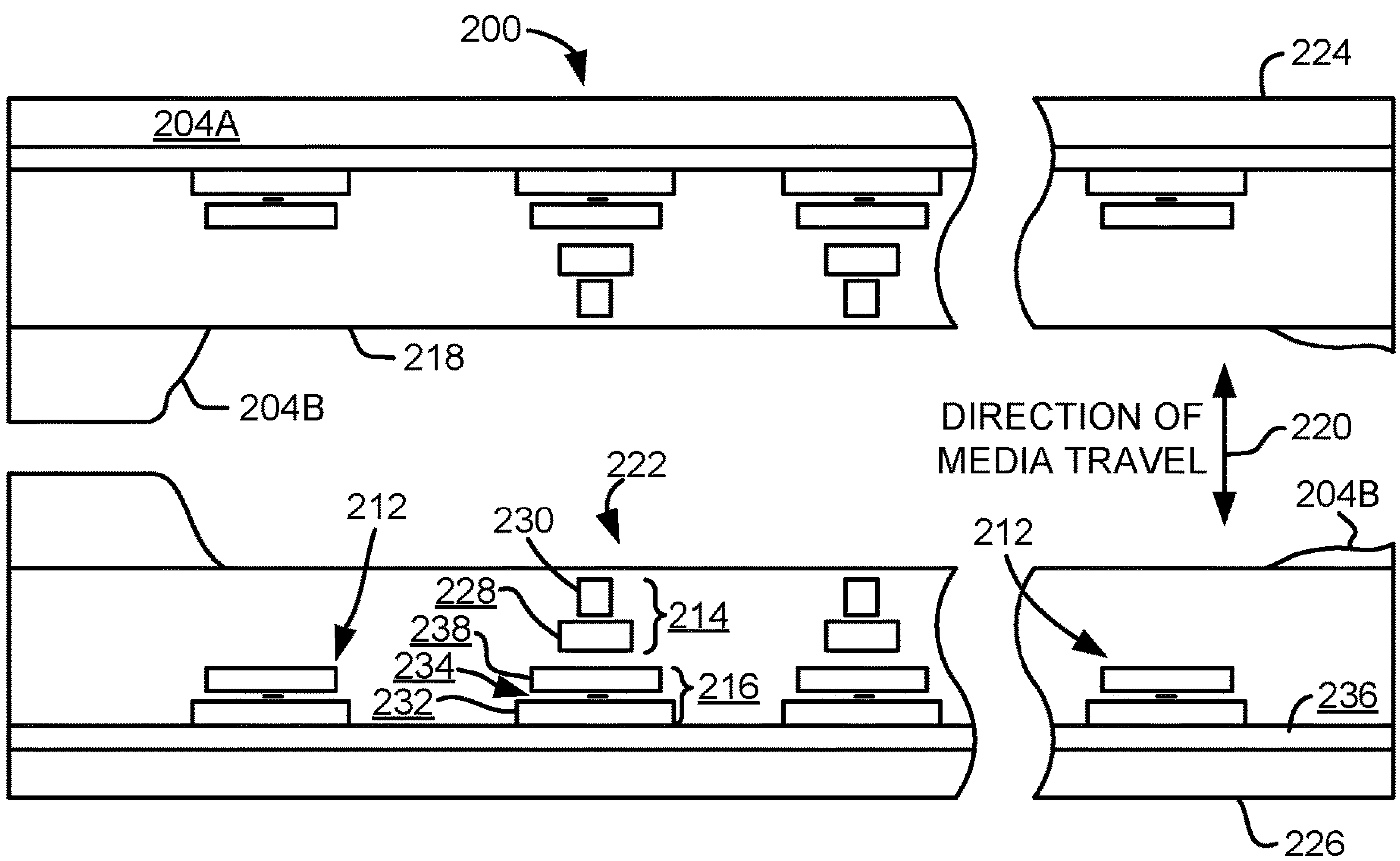
200
224
204A
218
204B
DIRECTION OF
MEDIA TRAVEL
220
222
212
230
204B
212
228
214
238
234
216
236
232
226

FIG. 2D

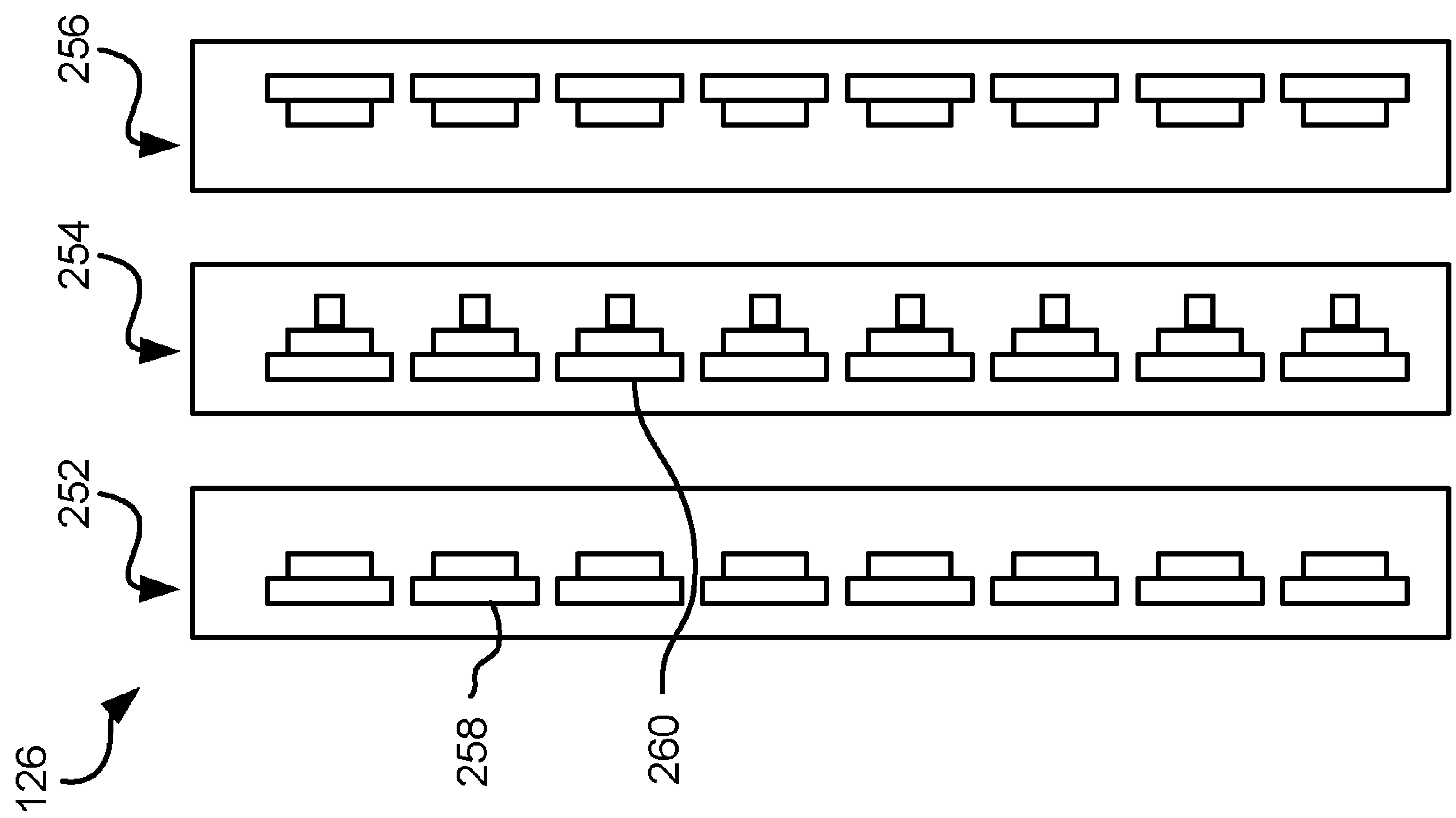

FIG. 4

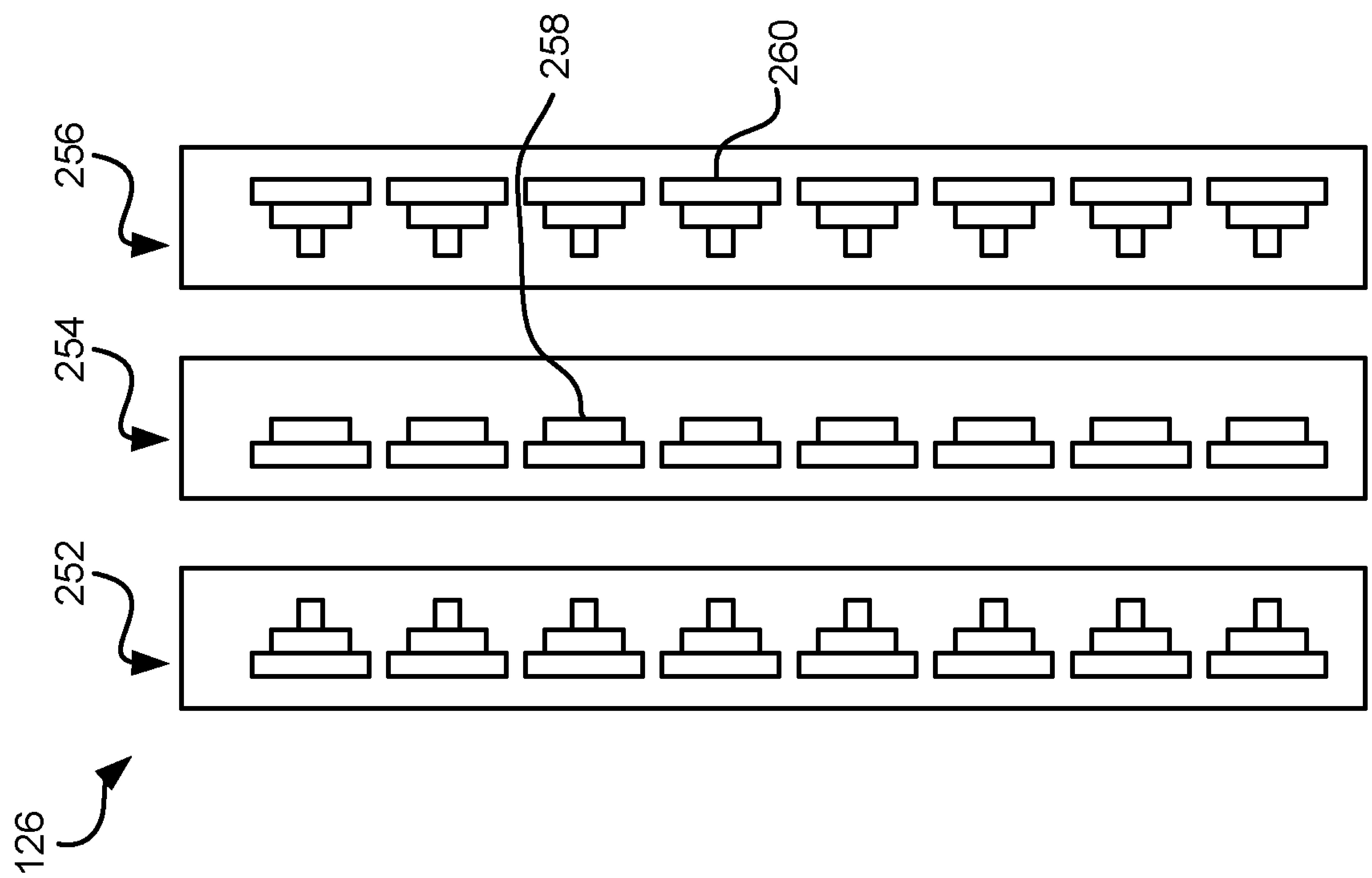

FIG. 3

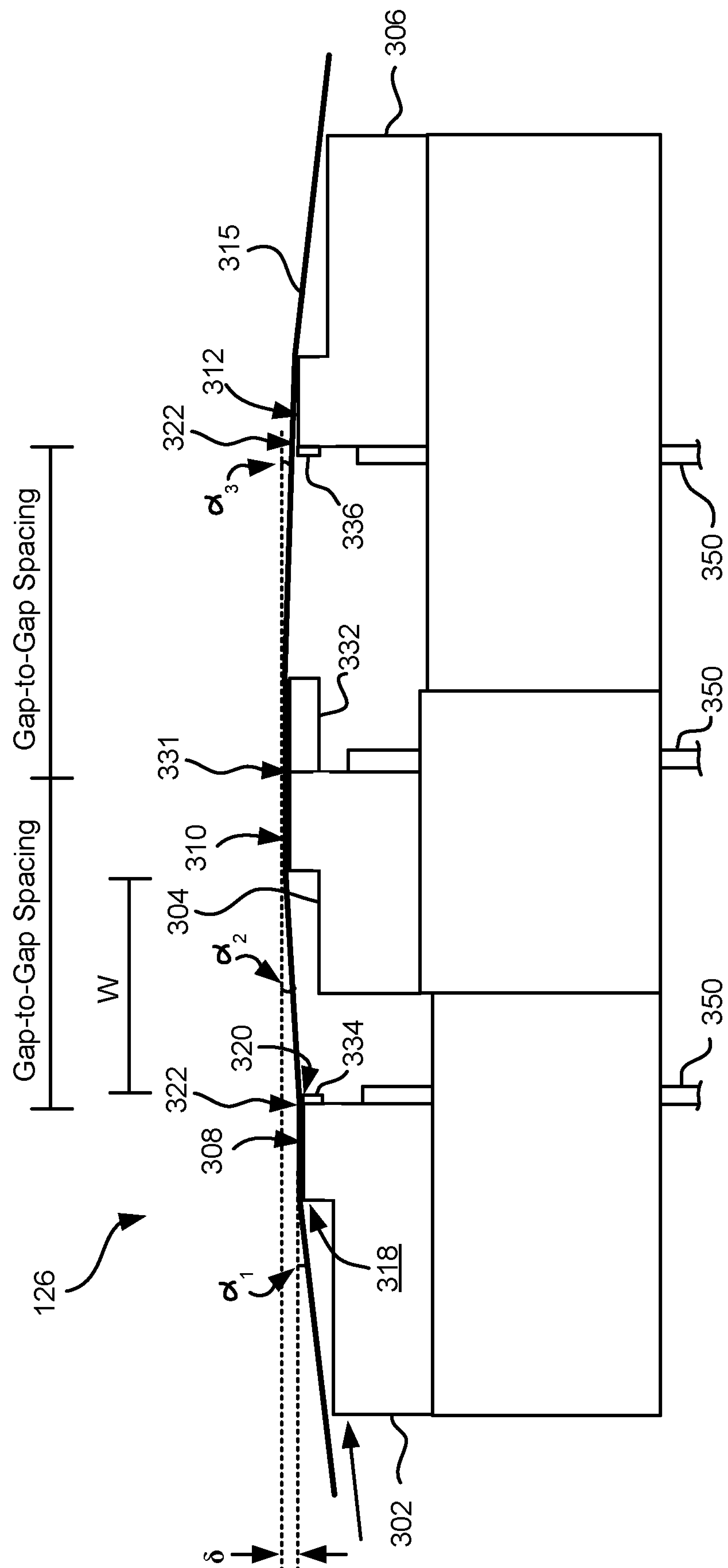
126
302
304
306
308
310
312
315
318
320
322
322
331
332
334
336
350
350
350
Gap-to-Gap Spacing
Gap-to-Gap Spacing
W
δ
α1
α2
α3

FIG. 5

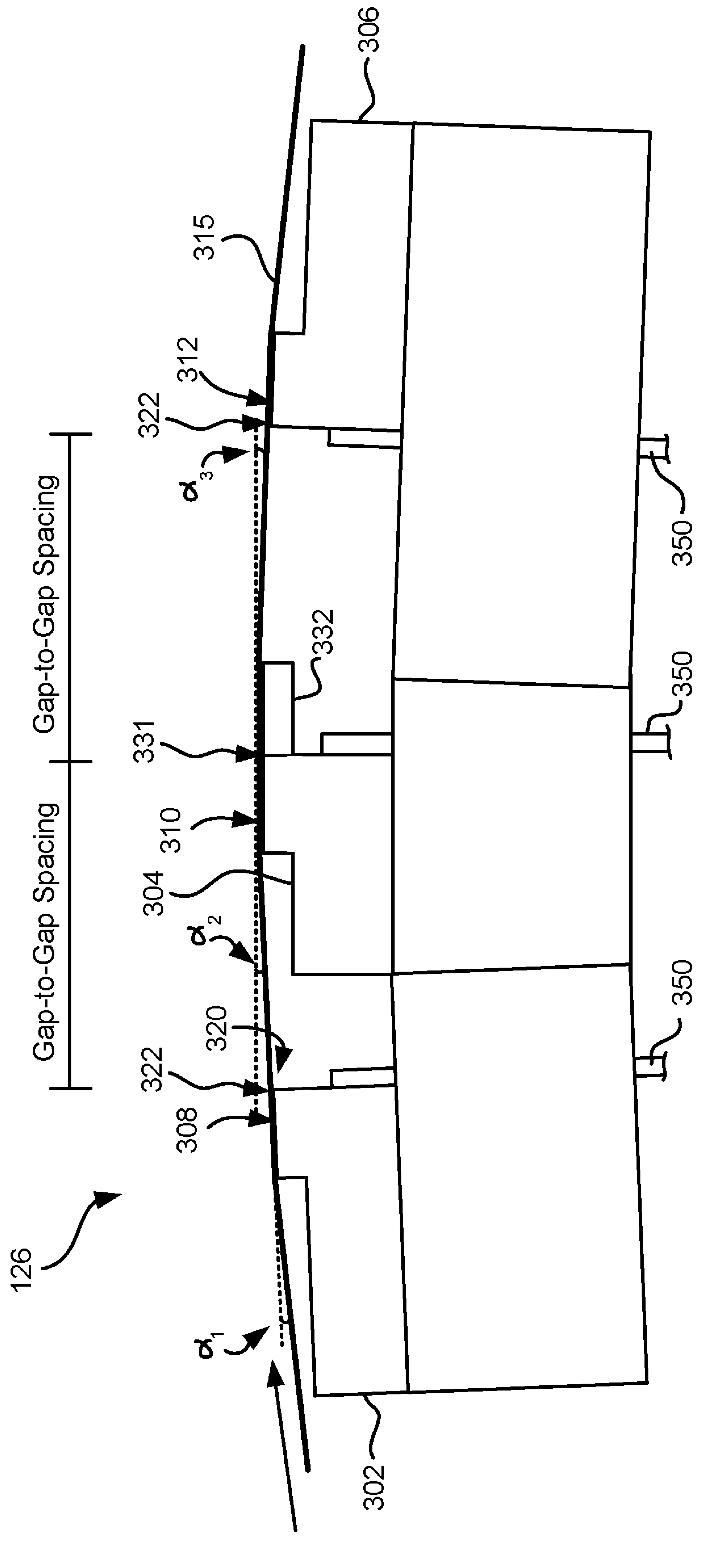
306
315
312
322
α_3
Gap-to-Gap Spacing
332
350
350
331
310
304
α_2
Gap-to-Gap Spacing
320
350
322
308
126
α_1
302

FIG. 6

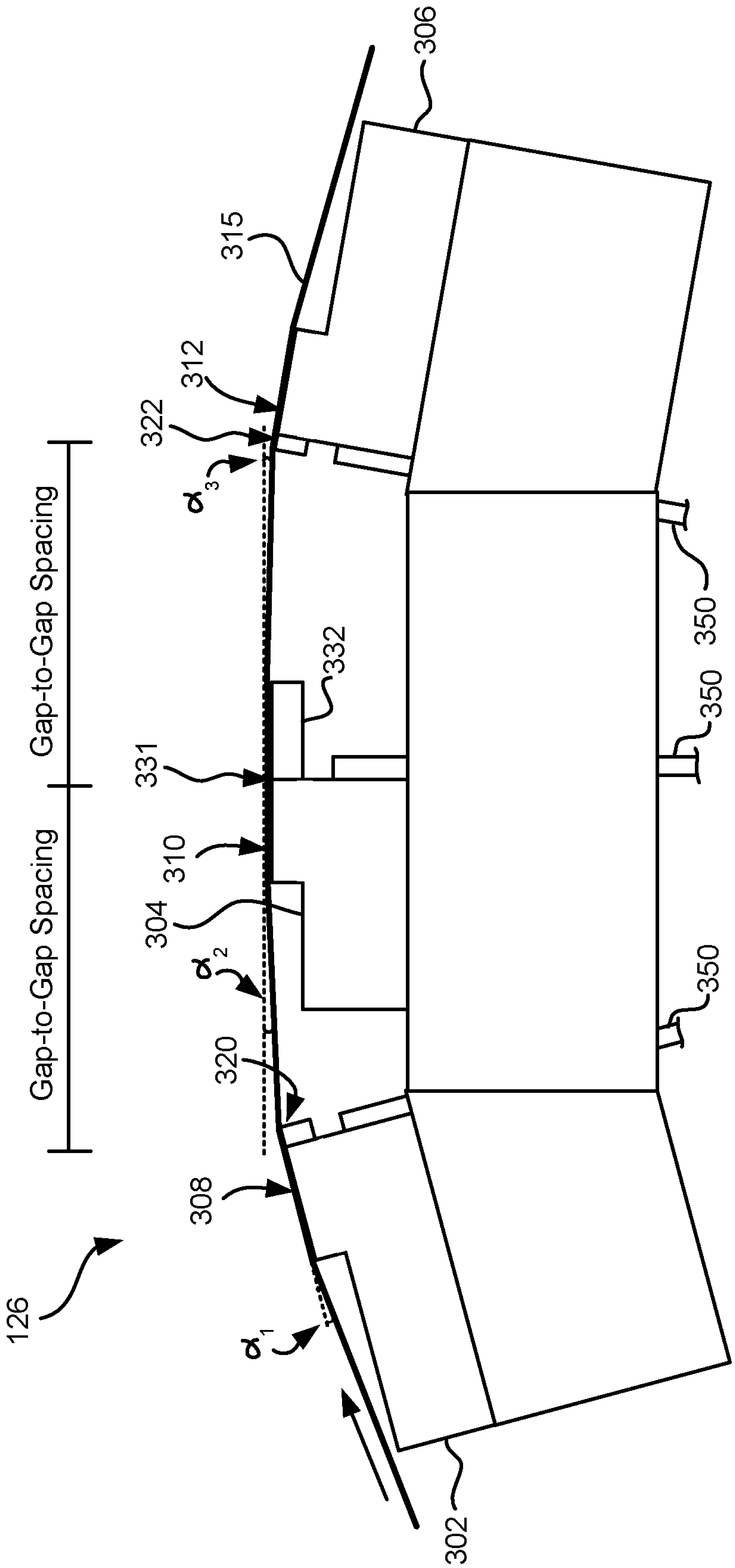
306
315
312
322
α_3
Gap-to-Gap Spacing
Gap-to-Gap Spacing
332
331
310
304
α_2
320
308
126
α_1
302
350
350
350

FIG. 7

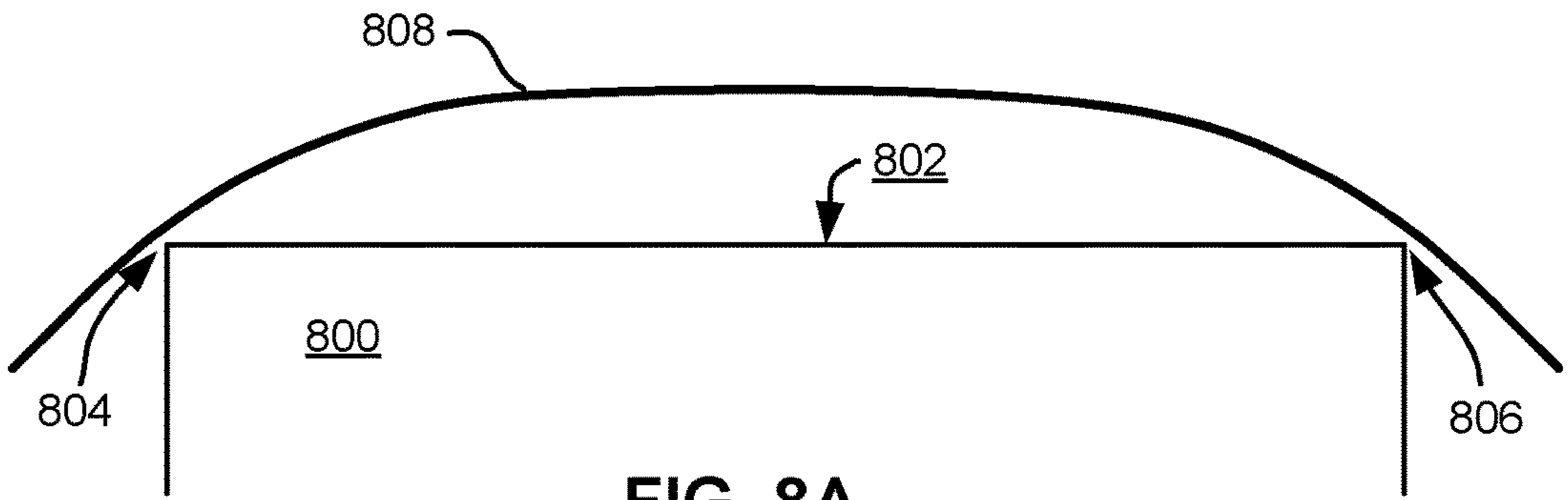

FIG. 8A

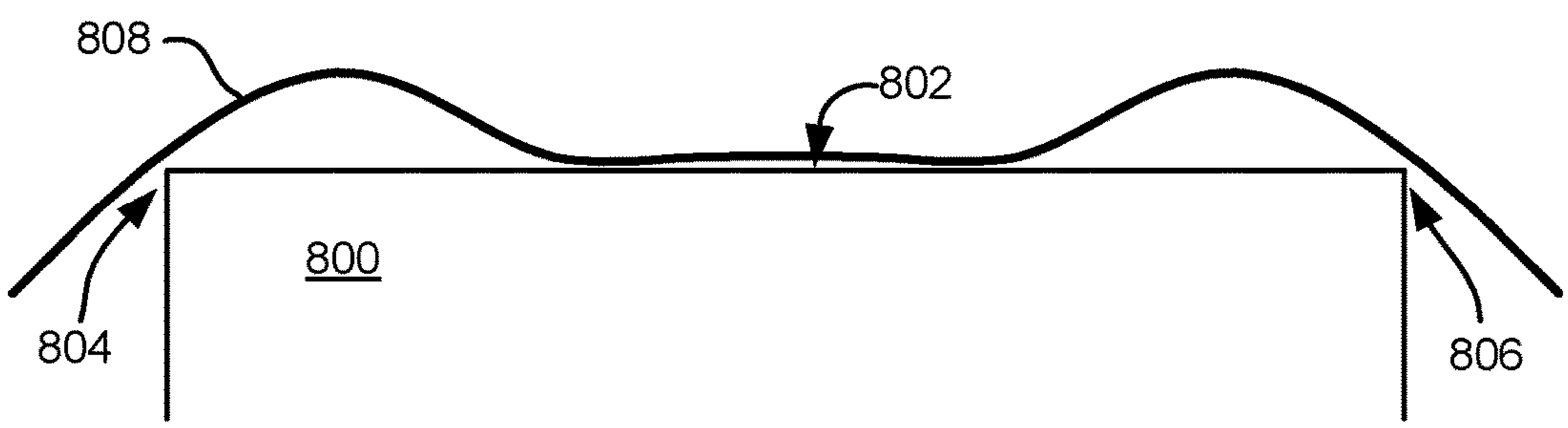

FIG. 8B

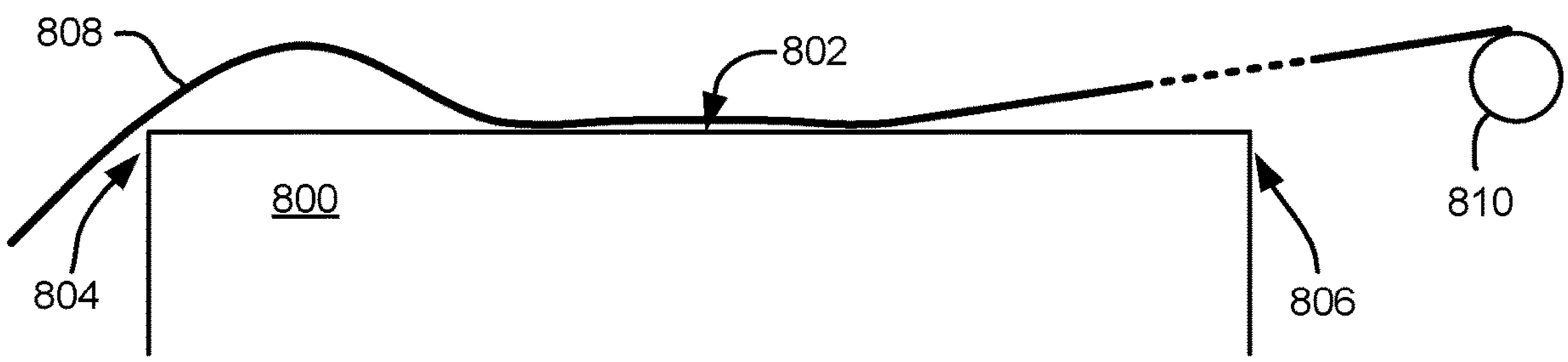

FIG. 8C

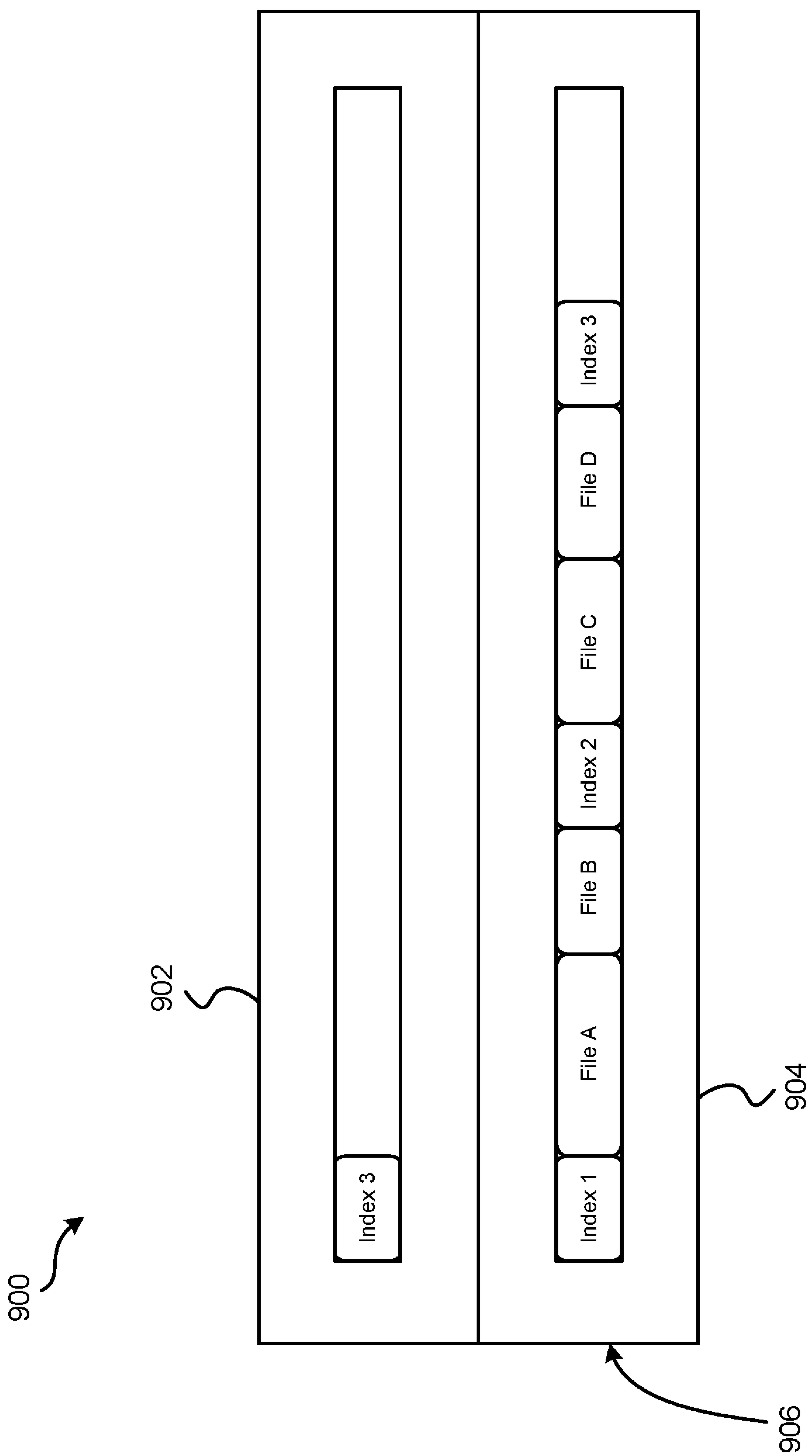
900
902
904
906
Index 3
Index 1
File A
File B
Index 2
File C
File D
Index 3

FIG. 9

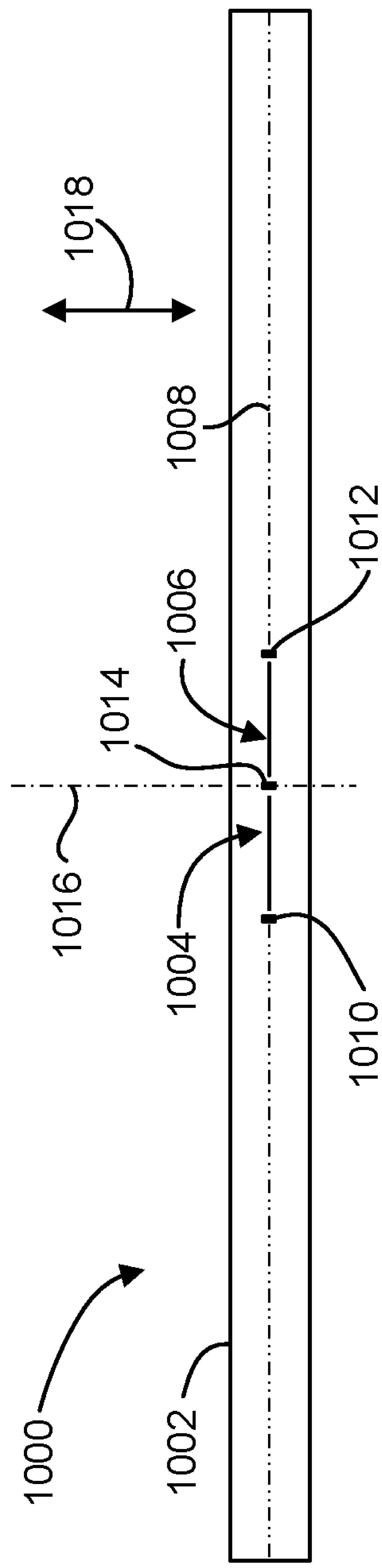
1018
1008
1012
1006
1014
1016
1004
1010
1000
1002

FIG. 10

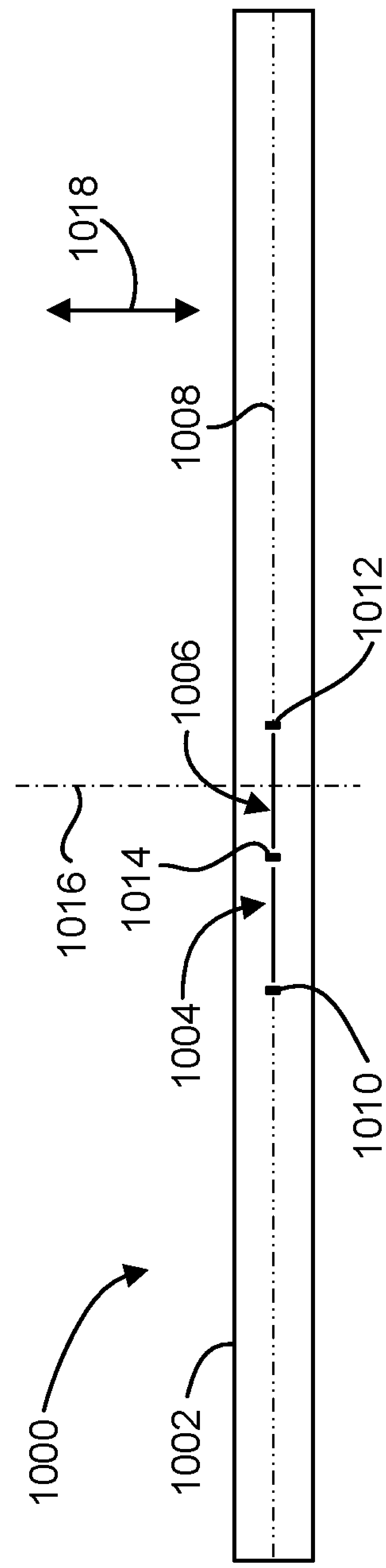
1018
1008
1012
1006
1016
1014
1004
1010
1000
1002

FIG. 11

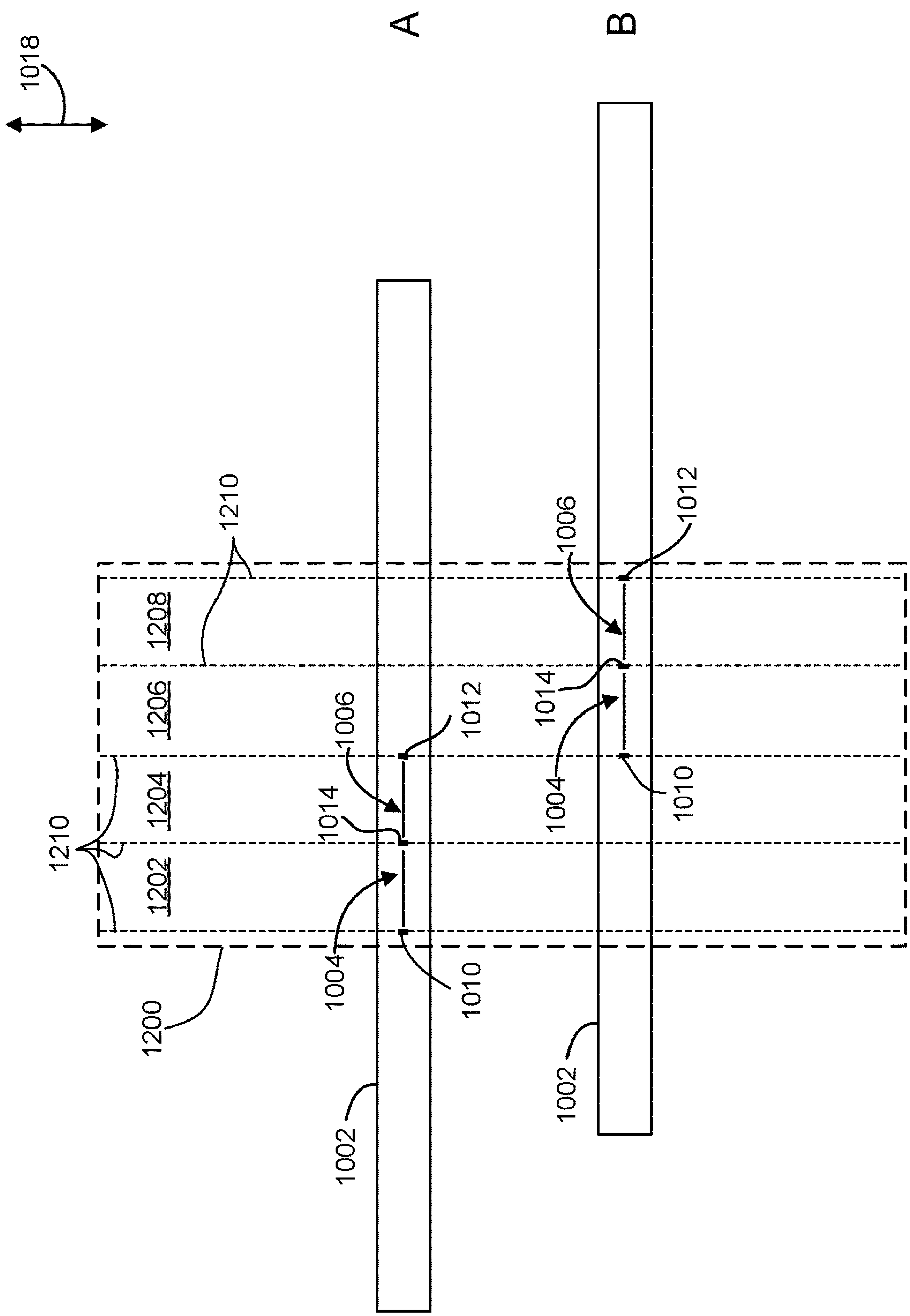
1018
A
B
1210
1208
1206
1204
1202
1210
1200
1006
1012
1014
1004
1010
1002
1006
1012
1014
1004
1010
1002

FIG. 12

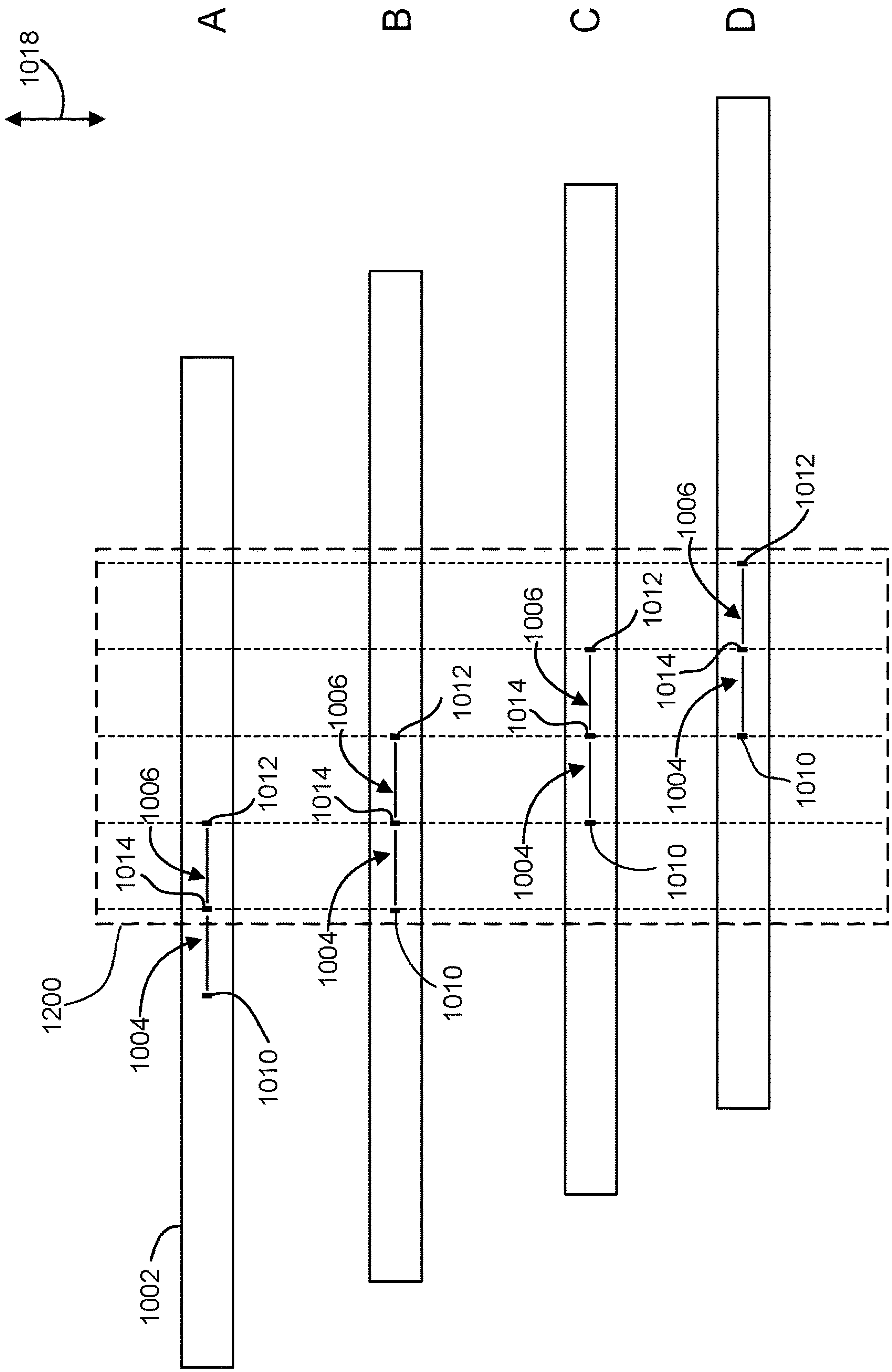

FIG. 13A

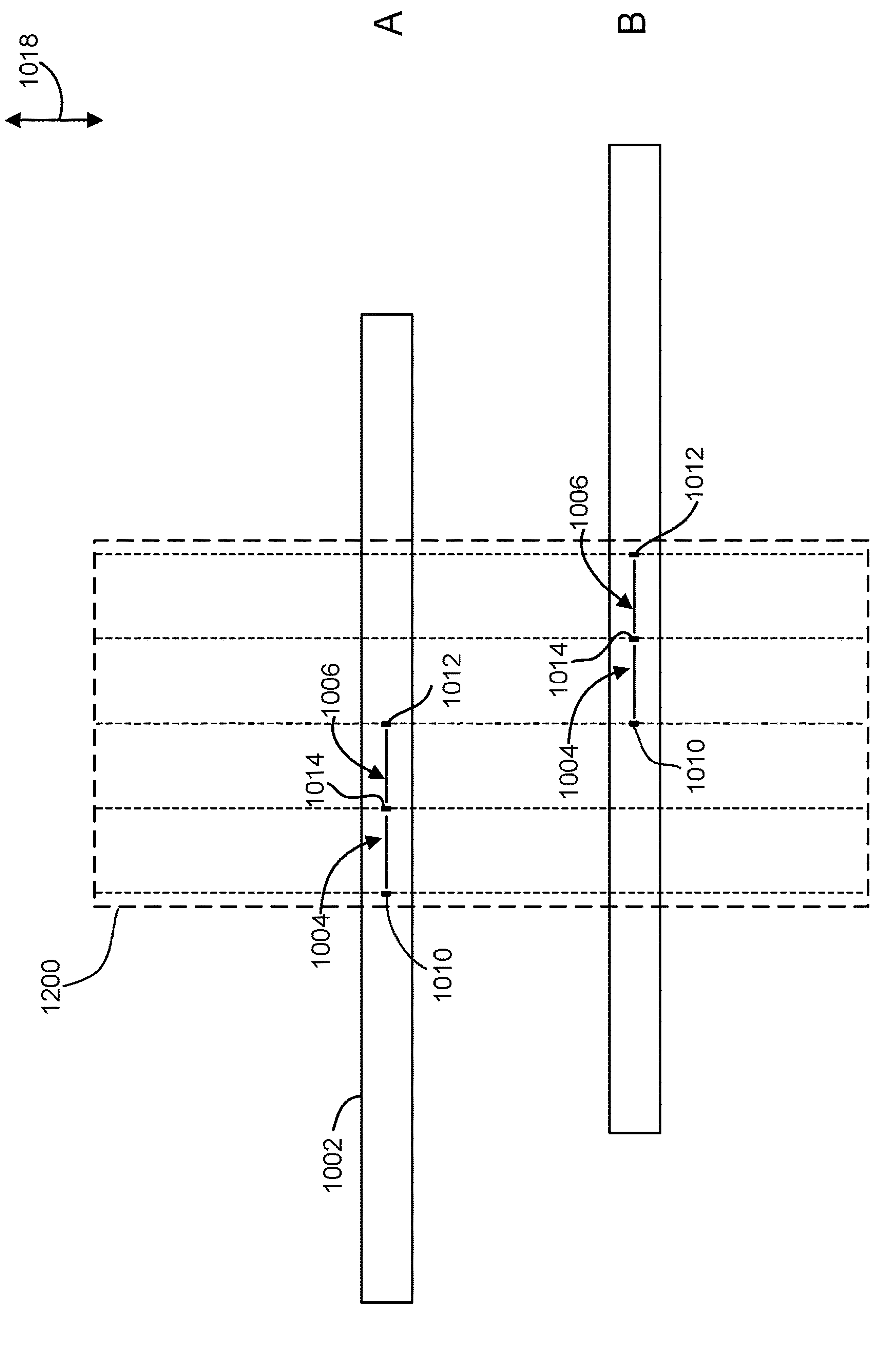

FIG. 13B

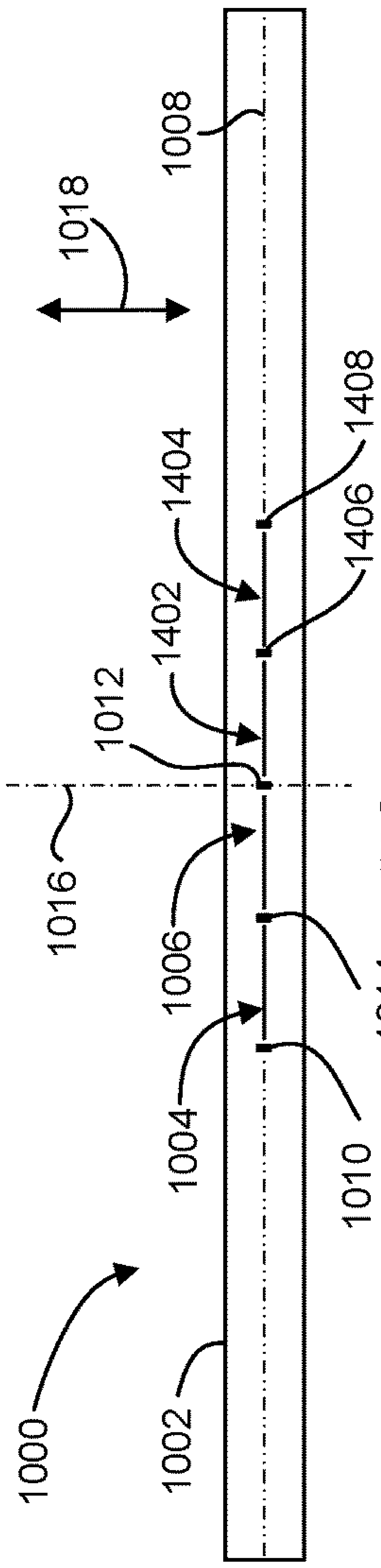

FIG. 14

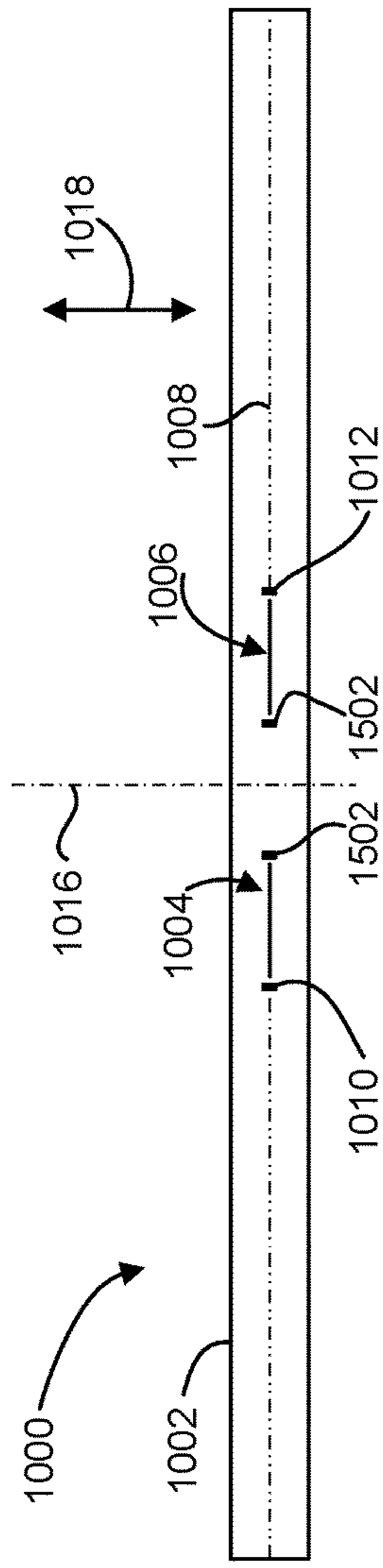

FIG. 15

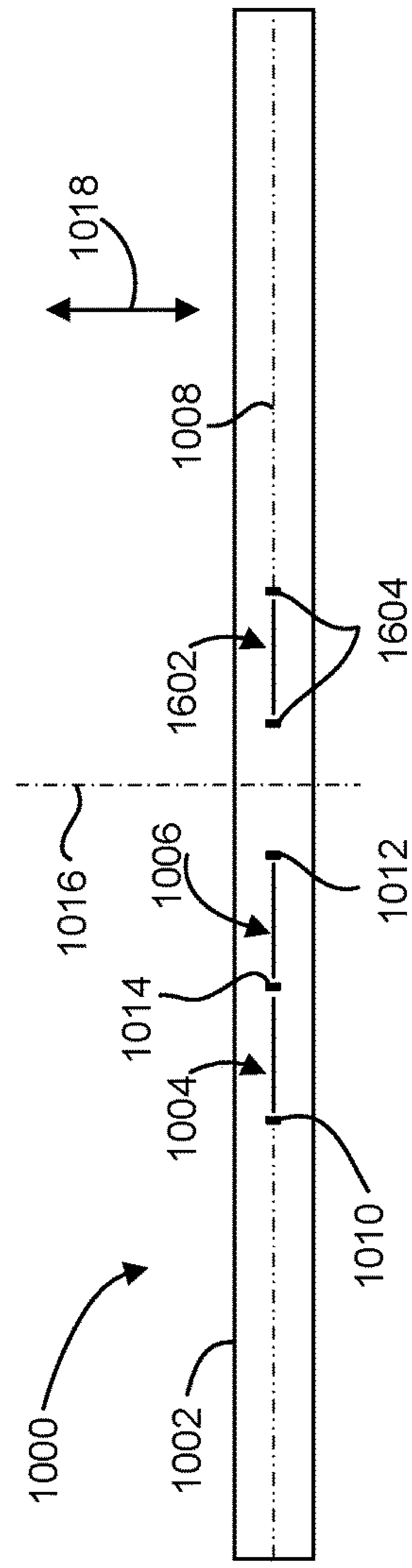

FIG. 16

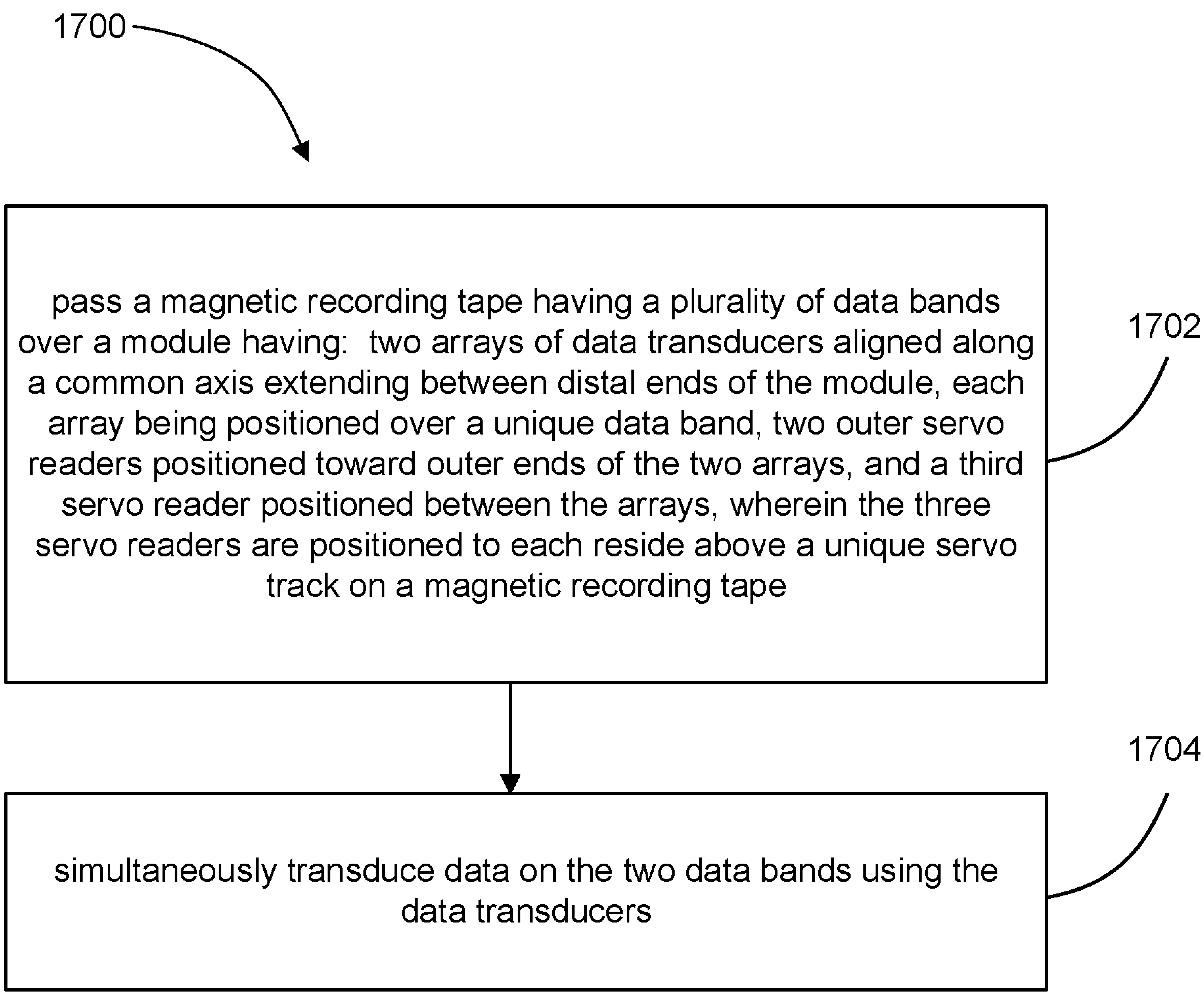
1700
pass a magnetic recording tape having a plurality of data bands over a module having: two arrays of data transducers aligned along a common axis extending between distal ends of the module, each array being positioned over a unique data band, two outer servo readers positioned toward outer ends of the two arrays, and a third servo reader positioned between the arrays, wherein the three servo readers are positioned to each reside above a unique servo track on a magnetic recording tape
1702
simultaneously transduce data on the two data bands using the data transducers
1704

FIG. 17

MULTI-BAND MULTICHANNEL MAGNETIC RECORDING HEAD

BACKGROUND

The present invention relates to data storage systems, and more particularly, this invention relates to magnetic recording heads for magnetic recording tape, and related systems.

In magnetic storage systems, magnetic transducers read data from and write data onto magnetic recording media. Data is written on the magnetic recording media by moving a magnetic recording transducer to a position over the media where the data is to be stored. The magnetic recording transducer then generates a magnetic field, which encodes the data into the magnetic media. Data is read from the media by similarly positioning the magnetic read transducer and then sensing the magnetic field of the magnetic media. Read and write operations may be independently synchronized with the movement of the media to ensure that the data can be read from and written to the desired location on the media.

An important and continuing goal in the data storage industry is that of increasing the density of data stored on a medium. For tape storage systems, that goal has led to increasing the track and linear bit density on recording tape, and decreasing the thickness of the magnetic tape medium. However, the development of small footprint, higher performance tape drive systems has created various challenges ranging from the design of tape head assemblies for use in such systems to dealing with tape dimensional instability. For example, increasing linear bit density dramatically increases vulnerability to spacing loss.

Some of the difficulties encountered when attempting to increase the number of concurrent channels in heads to enable increase in data rate per unit of tape speed are as follows. Conventionally, added channels are required to fit in the space between legacy servo readers to read and/or write within a single data band. This is done to preserve backward compatibility and ensure tape dimensional stability (TDS) problems do not increase. Thus, when channels are added to a given width (e.g., a data band width), the pitch between channels must be reduced. However, tighter pitch causes, for example, increase in crosstalk between writers, increase in writer coil resistance if thinner conductors are used, difficulty in managing greater congestion in the wiring layers, higher operating temperature due to the increased transducer density as well as higher coil resistance in writers or due to higher needed current due to removal of turns, etc. Moreover, as magnetic media goes to smaller magnetic particles in an effort to increase signal to noise ratio, more write flux is needed to penetrate the tape, which in turn requires generation of more field by the coils.

SUMMARY

The apparatuses and methods presented herein address difficulties encountered when attempting to increase the number of concurrent channels in heads to increase the data rate per unit of tape speed.

A method according to one approach includes passing a magnetic recording tape having a plurality of data bands over a module as described above. Data is simultaneously transduced on the two data bands using the data transducers. Advantageously, the number of simultaneously-usable channels on the module is dramatically increased, thereby also dramatically increasing the data rate per unit of tape speed, while backward compatibility may be preserved.

An apparatus, in accordance with one approach, includes a module having two arrays of data transducers thereon, the two arrays being aligned along a common axis extending between distal ends of the module. Outer servo readers are positioned toward outer ends of the two arrays. An inner servo reader is positioned between the two arrays. The servo readers are positioned to each reside above a unique servo track on a magnetic recording tape. This approach enables an increase in the simultaneously-usable number of channels in a head, while also enabling backward compatibility. A controller is configured to perform the aforementioned method.

Any of these approaches may be implemented in a magnetic data storage system such as a tape drive system, which may include a magnetic head, a drive mechanism for passing a magnetic medium (e.g., recording tape) over the magnetic head, and a controller electrically coupled to the magnetic head.

Other aspects of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a schematic diagram of a simplified tape drive system according to one approach.

FIG. **1**B is a schematic diagram of a tape cartridge according to one approach.

FIG. **2**A illustrates a side view of a flat-lapped, bi-directional, two-module magnetic tape head according to one approach.

FIG. **2**B is a tape bearing surface view taken from Line **2**B of FIG. **2**A.

FIG. **2**C is a detailed view taken from Circle **2**C of FIG. **2**B.

FIG. **2**D is a detailed view of a partial tape bearing surface of a pair of modules.

FIG. **3** is a partial tape bearing surface view of a magnetic head having a write-read-write configuration.

FIG. **4** is a partial tape bearing surface view of a magnetic head having a read-write-read configuration.

FIG. **5** is a side view of a magnetic tape head with three modules according to one approach where the modules all generally lie along about parallel planes.

FIG. **6** is a side view of a magnetic tape head with three modules in a tangent (angled) configuration.

FIG. **7** is a side view of a magnetic tape head with three modules in an overwrap configuration.

FIGS. **8**A-**8**C are schematics depicting the principles of tape tenting.

FIG. **9** is a representational diagram of files and indexes stored on a magnetic tape according to one approach.

FIG. **10** is a side view of an apparatus according to one approach.

FIG. **11** is a side view of the apparatus according to another approach.

FIG. **12** is a representational view of the apparatus of FIG. **10** in use according to one approach.

FIG. **13**A is a representational view of the apparatus of FIG. **10** in use according to one approach.

FIG. **13**B is a representational view of the apparatus of FIG. **11** in use according to one approach.

FIG. **14** is a side view of the apparatus according to another approach.

FIG. **15** is a side view of the apparatus according to another approach.

FIG. 16 is a side view of the apparatus according to another approach.

FIG. 17 is a flow diagram of a method according to one approach.

DETAILED DESCRIPTION

The following description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations.

Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the specification as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc.

It must also be noted that, as used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless otherwise specified.

The following description discloses several preferred approaches of magnetic storage systems, as well as operation and/or component parts thereof.

In one general approach, an apparatus includes two arrays of data transducers on a module, the two arrays being aligned along a common axis extending between distal ends of the module. Outer servo readers are positioned toward outer ends of the two arrays. An inner servo reader is positioned between the two arrays. The servo readers are positioned to each reside above a unique servo track on a magnetic recording tape.

In another general approach, a method according to one approach includes passing a magnetic recording tape having a plurality of data bands over a module as described above. Data is simultaneously transduced on the two data bands using the data transducers.

FIG. **1**A illustrates a simplified tape drive **100** of a tape-based data storage system, which may be employed in the context of the present invention. While one specific implementation of a tape drive is shown in FIG. **1**A, it should be noted that the approaches described herein may be implemented in the context of any type of tape drive system.

As shown, a tape supply cartridge **120** and a take-up reel **121** are provided to support a tape **122**. One or more of the reels may form part of a removable cartridge and are not necessarily part of the tape drive **100**. The tape drive, such as that illustrated in FIG. **1**A, may further include drive motor(s) to drive the tape supply cartridge **120** and the take-up reel **121** to move the tape **122** over a tape head **126** of any type. Such head may include an array of readers, writers, or both.

Guides **125** guide the tape **122** across the tape head **126**. Such tape head **126** is in turn coupled to a controller **128** via a cable **130**. The controller **128**, may be or include a processor and/or any logic for controlling any subsystem of the drive **100**. For example, the controller **128** typically controls head functions such as servo following, data writing, data reading, etc. The controller **128** may include at least one servo channel and at least one data channel, each of which include data flow processing logic configured to process and/or store information to be written to and/or read from the tape **122**. The controller **128** may operate under logic known in the art, as well as any logic disclosed herein, and thus may be considered as a processor for any of the descriptions of tape drives included herein, in various approaches. The controller **128** may be coupled to a memory **136** of any known type, which may store instructions executable by the controller **128**. Moreover, the controller **128** may be configured and/or programmable to perform or control some or all of the methodology presented herein. Thus, the controller **128** may be considered to be configured to perform various operations by way of logic programmed into one or more chips, modules, and/or blocks; software, firmware, and/or other instructions being available to one or more processors; etc., and combinations thereof.

The cable **130** may include read/write circuits to transmit data to the tape head **126** to be recorded on the tape **122** and to receive data read by the tape head **126** from the tape **122**. An actuator **132** controls position of the tape head **126** relative to the tape **122**.

An interface **134** may also be provided for communication between the tape drive **100** and a host (internal or external) to send and receive the data and for controlling the operation of the tape drive **100** and communicating the status of the tape drive **100** to the host, all as will be understood by those of skill in the art.

FIG. **1**B illustrates an exemplary tape cartridge **150** according to one approach. Such tape cartridge **150** may be used with a system such as that shown in FIG. **1**A. As shown, the tape cartridge **150** includes a housing **152**, a tape **122** in the housing **152**, and a nonvolatile memory **156** coupled to the housing **152**. In some approaches, the nonvolatile memory **156** may be embedded inside the housing **152**, as shown in FIG. **1**B. In more approaches, the nonvolatile memory **156** may be attached to the inside or outside of the housing **152** without modification of the housing **152**. For example, the nonvolatile memory may be embedded in a self-adhesive label **154**. In one preferred approach, the nonvolatile memory **156** may be a Flash memory device, read-only memory (ROM) device, etc., embedded into or coupled to the inside or outside of the tape cartridge **150**. The nonvolatile memory is accessible by the tape drive and the tape operating software (the driver software), and/or another device.

By way of example, FIG. **2**A illustrates a side view of a flat-lapped, bi-directional, two-module magnetic tape head **200** which may be implemented in the context of the present invention. As shown, the head includes a pair of bases **202**, each equipped with a module **204**, and fixed at a small angle α with respect to each other. The bases may be "U-beams" that are adhesively coupled together. Each module **204** includes a substrate **204**A and a closure **204**B with a thin film portion, commonly referred to as a "gap" in which the readers and/or writers **206** are formed. In use, a tape **208** is moved over the modules **204** along a media (tape) bearing surface **209** in the manner shown for reading and writing data on the tape **208** using the readers and writers. The wrap angle θ of the tape **208** at edges going onto and exiting the flat media support surfaces **209** are usually between about 0.1 degree and about 3 degrees.

The substrates **204**A are typically constructed of a wear resistant material, such as a ceramic. The closures **204**B may be made of the same or similar ceramic as the substrates **204**A.

The readers and writers may be arranged in a piggyback or merged configuration. An illustrative piggybacked configuration comprises a (magnetically inductive) writer transducer on top of (or below) a (magnetically shielded) reader transducer (e.g., a magnetoresistive reader, etc.), wherein the poles of the writer and the shields of the reader are generally separated. An illustrative merged configuration comprises one reader shield in the same physical layer as one writer pole (hence, "merged"). The readers and writers may also be arranged in an interleaved configuration. Alternatively, each array of channels may be readers or writers only. Any of these arrays may contain one or more servo track readers for reading servo data on the medium.

FIG. **2**B illustrates the tape bearing surface **209** of one of the modules **204** taken from Line **2**B of FIG. **2**A. A representative tape **208** is shown in dashed lines. The module **204** is preferably long enough to be able to support the tape as the head steps between data bands.

In this example, the tape **208** includes 4 to 32 data bands, e.g., with 16 data bands and 17 servo tracks **210**, as shown in FIG. **2**B on a one-half inch wide tape **208**. The data bands are defined between servo tracks **210**. Each data band may include a number of data tracks, for example 1024 data tracks (not shown). During read/write operations, the readers and/or writers **206** are positioned to specific track positions within one of the data bands. Outer readers, sometimes called servo readers, read the servo tracks **210**. The servo signals are in turn used for track following, i.e., to keep the readers and/or writers **206** aligned with a particular set of tracks during the read/write operations.

FIG. **2**C depicts a plurality of readers and/or writers **206** formed in a gap **218** on the module **204** in Circle **2**C of FIG. **2**B. As shown, the array of readers and writers **206** includes, for example, 16 writers **214**, 16 readers **216** and two servo readers **212**, though the number of elements may vary. Illustrative approaches include 8, 16, 32, 40, and 64 active readers and/or writers **206** per array, and alternatively interleaved designs having odd numbers of reader or writers such as 17, 25, 33, etc. An illustrative approach includes 32 readers per array and/or 32 writers per array, where the actual number of transducer elements could be greater, e.g., 33, 34, etc. This allows the tape to travel more slowly, thereby reducing speed-induced tracking and mechanical difficulties and/or execute fewer "wraps" to fill or read the tape. While the readers and writers may be arranged in a piggyback configuration as shown in FIG. **2**C, the readers **216** and writers **214** may also be arranged in an interleaved configuration. Alternatively, each array of readers and/or writers **206** may be readers or writers only, and the arrays may contain one or more servo readers **212**. As noted by considering FIGS. **2**A and **2**B-**2**C together, each module **204** may include a complementary set of readers and/or writers **206** for such things as bi-directional reading and writing, read-while-write capability, backward compatibility, etc.

FIG. **2**D shows a partial tape bearing surface view of complementary modules of a magnetic tape head **200** according to one approach. In this approach, each module has a plurality of read/write (R/W) pairs in a piggyback configuration formed on a common substrate **204**A and an optional electrically insulative insulating layer **236**. The writers **214** and the readers **216** are aligned parallel to an intended direction of travel of a tape medium thereacross to form an R/W pair, exemplified by R/W pairs **222**. Note that the intended direction of tape travel is sometimes referred to herein as the direction of tape travel, and such terms may be used interchangeably. Such direction of tape travel may be inferred from the design of the system, e.g., by examining the guides; observing the actual direction of tape travel relative to the reference point; etc. Moreover, in a system operable for bi-direction reading and/or writing, the direction of tape travel in both directions is typically parallel and thus both directions may be considered equivalent to each other.

Several R/W pairs **222** may be present, such as 8, 16, 32 pairs, etc. The R/W pairs **222** as shown are linearly aligned in a direction generally perpendicular to a direction of tape travel thereacross. However, the pairs may also be aligned diagonally, etc. Servo readers **212** are positioned on the outside of the array of R/W pairs, the function of which is well known.

Generally, the magnetic tape medium moves in either a forward or reverse direction as indicated by arrow **220**. The magnetic tape medium and head assembly **200** operate in a transducing relationship in the manner well-known in the art. The head assembly **200** includes two thin-film modules **224** and **226** of generally identical construction.

Modules **224** and **226** are joined together with a space present between closures **204**B thereof (partially shown) to form a single physical unit to provide read-while-write capability by activating the writer of the leading module and reader of the trailing module aligned with the writer of the leading module parallel to the direction of tape travel relative thereto. When a module **224**, **226** of a magnetic tape head **200** is constructed, layers are formed in the gap **218** created above an electrically conductive substrate **204**A (partially shown), e.g., of AlTiC, in generally the following order for the R/W pairs **222**: an insulating layer **236**, a first shield **232** typically of an iron alloy such as NiFe (–), cobalt zirconium tantalum (CZT) or Al—Fe—Si (Sendust), a sensor **234** for sensing a data track on a magnetic medium, a second shield **238** typically of a nickel-iron alloy (e.g., ~80/20 at % NiFe, also known as permalloy), first and second writer poles **228**, **230**, and a coil (not shown). The sensor may be of any known type, including those based on magnetoresistive (MR), GMR, AMR, tunneling magnetoresistance (TMR), etc.

The first and second writer poles **228**, **230** may be fabricated from high magnetic moment materials such as ~45/55 NiFe. Note that these materials are provided by way of example only, and other materials may be used. Additional layers such as insulation between the shields and/or pole tips and an insulation layer surrounding the sensor may be present. Illustrative materials for the insulation include alumina and other oxides, insulative polymers, etc.

The configuration of the tape head **126** according to one approach includes multiple modules, preferably three or more. In a write-read-write (W-R-W) head, outer modules for writing flank one or more inner modules for reading. Referring to FIG. **3**, depicting a W-R-W configuration, the outer modules **252**, **256** each include one or more arrays of writers **260**. The inner module **254** of FIG. **3** includes one or more arrays of readers **258** in a similar configuration. Variations of a multi-module head include a R-W-R head (FIG. **4**), a R-R-W head, a W-W-R head, etc. In yet other variations, one or more of the modules may have read/write pairs of transducers. Moreover, more than three modules may be present. In further approaches, two outer modules may flank two or more inner modules, e.g., in a W-R-R-W, a R-W-W-R arrangement, etc. For simplicity, a W-R-W head is used primarily herein to exemplify approaches of the present invention. One skilled in the art apprised with the teachings herein will appreciate how permutations of the present invention would apply to configurations other than a W-R-W configuration.

FIG. **5** illustrates a magnetic head **126** according to one approach of the present invention that includes first, second and third modules **302**, **304**, **306** each having a tape bearing surface **308**, **310**, **312** respectively, which may be flat, contoured, etc. Note that while the term "tape bearing surface" appears to imply that the surface facing the tape **315** is in physical contact with the tape bearing surface, this is not necessarily the case. Rather, only a portion of the tape may be in contact with the tape bearing surface, constantly or intermittently, with other portions of the tape riding (or "flying") above the tape bearing surface on a layer of air, sometimes referred to as an "air bearing". The first module **302** will be referred to as the "leading" module as it is the first module encountered by the tape in a three module design for tape moving in the indicated direction. The third module **306** will be referred to as the "trailing" module. The trailing module follows the middle module and is the last module seen by the tape in a three module design. The leading and trailing modules **302**, **306** are referred to collectively as outer modules. Also note that the outer modules **302**, **306** will alternate as leading modules, depending on the direction of travel of the tape **315**.

In one approach, the tape bearing surfaces **308**, **310**, **312** of the first, second and third modules **302**, **304**, **306** lie on about parallel planes (which is meant to include parallel and nearly parallel planes, e.g., between parallel and tangential as in FIG. **6**), and the tape bearing surface **310** of the second module **304** is above the tape bearing surfaces **308**, **312** of the first and third modules **302**, **306**. As described below, this has the effect of creating the desired wrap angle α_2 of the tape relative to the tape bearing surface **310** of the second module **304**.

Where the tape bearing surfaces **308**, **310**, **312** lie along parallel or nearly parallel yet offset planes, intuitively, the tape should peel off of the tape bearing surface **308** of the leading module **302**. However, the vacuum created by a skiving edge **318** of the leading module **302** has been found by experimentation to be sufficient to keep the tape adhered to the tape bearing surface **308** of the leading module **302**. A trailing edge **320** of the leading module **302** (the end from which the tape leaves the leading module **302**) is the approximate reference point which defines the wrap angle α_2 over the tape bearing surface **310** of the second module **304**. The tape stays in close proximity to the tape bearing surface until close to the trailing edge **320** of the leading module **302**. Accordingly, transducers **322** may be located near the trailing edges of the outer modules **302**, **306**. These approaches are particularly adapted for write-read-write applications.

A benefit of this and other approaches described herein is that, because the outer modules **302**, **306** are fixed at a determined offset from the second module **304**, the inner wrap angle α_2 is fixed when the modules **302**, **304**, **306** are coupled together or are otherwise fixed into a head. The inner wrap angle α_2 is approximately $\tan^{-1}(\delta/W)$ where δ is the height difference between the planes of the tape bearing surfaces **308**, **310** and W is the width between the opposing ends of the tape bearing surfaces **308**, **310**. An illustrative inner wrap angle α_2 is in a range of about 0.3° to about 1.1°, though can be any angle required by the design.

Beneficially, the inner wrap angle α_2 on the side of the module **304** receiving the tape (leading edge) will be larger than the inner wrap angle α**3** on the trailing edge, as the tape **315** rides above the trailing module **306**. This difference is generally beneficial as a smaller α_3 tends to oppose what has heretofore been a steeper exiting effective wrap angle.

Note that the tape bearing surfaces **308**, **312** of the outer modules **302**, **306** are positioned to achieve a negative wrap angle at the trailing edge **320** of the leading module **302**. This is generally beneficial in helping to reduce friction due to contact with the trailing edge **320**, provided that proper consideration is given to the location of the crowbar region that forms in the tape where it peels off the head. This negative wrap angle also reduces flutter and scrubbing damage to the elements on the leading module **302**. Further, at the trailing module **306**, the tape **315** flies over the tape bearing surface **312** so there is virtually no wear on the elements when tape is moving in this direction. Particularly, the tape **315** entrains air and so will not significantly ride on the tape bearing surface **312** of the third module **306** (some contact may occur). This is permissible, because the leading module **302** is writing while the trailing module **306** is idle.

Writing and reading functions are performed by different modules at any given time. In one approach, the second module **304** includes a plurality of data and optional servo readers **331** and no writers. The first and third modules **302**, **306** include a plurality of writers **322** and no data readers, with the exception that the outer modules **302**, **306** may include optional servo readers. The servo readers may be used to position the head during reading and/or writing operations. The servo reader(s) on each module are typically located towards the end of the array of readers or writers.

By having only readers or side by side writers and servo readers in the gap between the substrate and closure, the gap length can be substantially reduced. Typical heads have piggybacked readers and writers, where the writer is formed above each reader. A typical gap is 20-35 microns. However, irregularities on the tape may tend to droop into the gap and create gap erosion. Thus, the smaller the gap is the better. The smaller gap enabled herein exhibits fewer wear related problems.

In some aspects, the second module **304** has a closure, while the first and third modules **302**, **306** do not have a closure. Where there is no closure, preferably a hard coating is added to the module. One preferred coating is diamond-like carbon (DLC).

In the approach shown in FIG. **5**, the first, second, and third modules **302**, **304**, **306** each have a closure **332**, **334**, **336**, which extends the tape bearing surface of the associated module, thereby effectively positioning the read/write elements away from the edge of the tape bearing surface. The closure **332** on the second module **304** can be a ceramic closure of a type typically found on tape heads. The closures **334**, **336** of the first and third modules **302**, **306**, however, may be shorter than the closure **332** of the second module **304** as measured parallel to a direction of tape travel over the respective module. This enables positioning the modules closer together. One way to produce shorter closures **334**, **336** is to lap the standard ceramic closures of the second module **304** an additional amount. Another way is to plate or deposit thin film closures above the elements during thin film processing. For example, a thin film closure of a hard material such as Sendust or nickel-iron alloy (e.g., 45/55) can be formed on the module.

With reduced-thickness ceramic or thin film closures **334**, **336** or no closures on the outer modules **302**, **306**, the write-to-read gap spacing can be reduced to less than about 1 mm, e.g., about 0.75 mm, or 50% less than commonly-used linear tape open (LTO) tape head spacing. The open space between the modules **302**, **304**, **306** can still be set to approximately 0.5 to 0.6 mm, which in some approaches is ideal for stabilizing tape motion over the second module **304**.

Depending on tape tension and stiffness, it may be desirable to angle the tape bearing surfaces of the outer modules relative to the tape bearing surface of the second module. FIG. **6** illustrates an approach where the modules **302**, **304**, **306** are in a tangent or nearly tangent (angled) configuration. Particularly, the tape bearing surfaces of the outer modules **302**, **306** are about parallel to the tape at the desired wrap angle α_2 of the second module **304**. In other words, the planes of the tape bearing surfaces **308**, **312** of the outer modules **302**, **306** are oriented at about the desired wrap angle α_2 of the tape **315** relative to the second module **304**. The tape will also pop off of the trailing module **306** in this approach, thereby reducing wear on the elements in the trailing module **306**. These approaches are particularly useful for write-read-write applications. Additional aspects of these approaches are similar to those given above.

Typically, the tape wrap angles may be set about midway between the approaches shown in FIGS. **5** and **6**.

FIG. **7** illustrates an approach where the modules **302**, **304**, **306** are in an overwrap configuration. Particularly, the tape bearing surfaces **308**, **312** of the outer modules **302**, **306** are angled slightly more than the tape **315** when set at the desired wrap angle α_2 relative to the second module **304**. In this approach, the tape does not pop off of the trailing module, allowing it to be used for writing or reading. Accordingly, the leading and middle modules can both perform reading and/or writing functions while the trailing module can read any just-written data. Thus, these approaches are preferred for write-read-write, read-write-read, and write-write-read applications. In the latter approaches, closures should be wider than the tape canopies for ensuring read capability. The wider closures may require a wider gap-to-gap separation. Therefore, a preferred approach has a write-read-write configuration, which may use shortened closures that thus allow closer gap-to-gap separation.

Additional aspects of the approaches shown in FIGS. **6** and **7** are similar to those given above.

A 32 channel version of a multi-module tape head **126** may use cables **350** having leads on the same or smaller pitch as current 16 channel piggyback LTO modules, or alternatively the connections on the module may be organ-keyboarded for a 50% reduction in cable span. Over-under, writing pair unshielded cables may be used for the writers, which may have integrated servo readers.

The outer wrap angles α_1 may be set in the drive, such as by guides of any type known in the art, such as adjustable rollers, slides, etc. or alternatively by outriggers, which are integral to the head. For example, rollers having an offset axis may be used to set the wrap angles. The offset axis creates an orbital arc of rotation, allowing precise alignment of the wrap angle α_1.

To assemble any of the approaches described above, conventional u-beam assembly can be used. Accordingly, the mass of the resultant head may be maintained or even reduced relative to heads of previous generations. In other approaches, the modules may be constructed as a unitary body. Those skilled in the art, armed with the present teachings, will appreciate that other known methods of manufacturing such heads may be adapted for use in constructing such heads. Moreover, unless otherwise specified, processes and materials of types known in the art may be adapted for use in various approaches in conformance with the teachings herein, as would become apparent to one skilled in the art upon reading the present disclosure.

As a tape is run over a module, it is preferred that the tape passes sufficiently close to magnetic transducers on the module such that reading and/or writing is efficiently performed, e.g., with a low error rate. According to some approaches, tape tenting may be used to ensure the tape passes sufficiently close to the portion of the module having the magnetic transducers. To better understand this process, FIGS. **8A-8C** illustrate the principles of tape tenting. FIG. **8A** shows a module **800** having an upper tape bearing surface **802** extending between opposite edges **804**, **806**. A stationary tape **808** is shown wrapping around the edges **804**, **806**. As shown, the bending stiffness of the tape **808** lifts the tape off of the tape bearing surface **802**. Tape tension tends to flatten the tape profile, as shown in FIG. **8A**. Where tape tension is minimal, the curvature of the tape is more parabolic than shown.

FIG. **8B** depicts the tape **808** in motion. The leading edge, i.e., the first edge the tape encounters when moving, may serve to skive air from the tape, thereby creating a subambient air pressure between the tape **808** and the tape bearing surface **802**. In FIG. **8B**, the leading edge is the left edge and the right edge is the trailing edge when the tape is moving left to right. As a result, atmospheric pressure above the tape urges the tape toward the tape bearing surface **802**, thereby creating tape tenting proximate each of the edges. The tape bending stiffness resists the effect of the atmospheric pressure, thereby causing the tape tenting proximate both the leading and trailing edges. Modeling predicts that the two tents are very similar in shape.

FIG. **8C** depicts how the subambient pressure urges the tape **808** toward the tape bearing surface **802** even when a trailing guide **810** is positioned above the plane of the tape bearing surface.

It follows that tape tenting may be used to direct the path of a tape as it passes over a module. As previously mentioned, tape tenting may be used to ensure the tape passes sufficiently close to the portion of the module having the magnetic transducers, preferably such that reading and/or writing is efficiently performed, e.g., with a low error rate.

Magnetic tapes may be stored in tape cartridges that are, in turn, stored at storage slots or the like inside a data storage library. The tape cartridges may be stored in the library such that they are accessible for physical retrieval. In addition to magnetic tapes and tape cartridges, data storage libraries may include data storage drives that store data to, and/or retrieve data from, the magnetic tapes. Moreover, tape libraries and the components included therein may implement a file system which enables access to tape and data stored on the tape.

File systems may be used to control how data is stored in, and retrieved from, memory. Thus, a file system may include the processes and data structures that an operating system uses to keep track of files in memory, e.g., the way the files are organized in memory. Linear Tape File System (LTFS) is an exemplary format of a file system that may be implemented in a given library in order to enables access to compliant tapes. It should be appreciated that various approaches herein can be implemented with a wide range of file system formats, including for example IBM Spectrum Archive Library Edition (LTFS LE). However, to provide a context, and solely to assist the reader, some of the approaches below may be described with reference to LTFS which is a type of file system format. This has been done by way of example only, and should not be deemed limiting on the invention defined in the claims.

A tape cartridge may be "loaded" by inserting the cartridge into the tape drive, and the tape cartridge may be "unloaded" by removing the tape cartridge from the tape drive. Once loaded in a tape drive, the tape in the cartridge may be "threaded" through the drive by physically pulling the tape (the magnetic recording portion) from the tape cartridge, and passing it above a magnetic head of a tape drive. Furthermore, the tape may be attached on a take-up reel (e.g., see **121** of FIG. **1A** above) to move the tape over the magnetic head.

Once threaded in the tape drive, the tape in the cartridge may be "mounted" by reading metadata on a tape and bringing the tape into a state where the LTFS is able to use the tape as a constituent component of a file system. Moreover, in order to "unmount" a tape, metadata is preferably first written on the tape (e.g., as an index), after which the tape may be removed from the state where the LTFS is allowed to use the tape as a constituent component of a file system. Finally, to "unthread" the tape, the tape is unattached from the take-up reel and is physically placed back into the inside of a tape cartridge again. The cartridge may remain loaded in the tape drive even after the tape has been unthreaded, e.g., waiting for another read and/or write request. However, in other instances, the tape cartridge may be unloaded from the tape drive upon the tape being unthreaded, e.g., as described above.

Magnetic tape is a sequential access medium. Thus, new data is written to the tape by appending the data at the end of previously written data. It follows that when data is recorded in a tape having only one partition, metadata (e.g., allocation information) is continuously appended to an end of the previously written data as it frequently updates and is accordingly rewritten to tape. As a result, the rearmost information is read when a tape is first mounted in order to access the most recent copy of the metadata corresponding to the tape. However, this introduces a considerable amount of delay in the process of mounting a given tape.

To overcome this delay caused by single partition tape mediums, the LTFS format includes a tape that is divided into two partitions, which include an index partition and a data partition. The index partition may be configured to record metadata (meta information), e.g., such as file allocation information (Index), while the data partition may be configured to record the body of the data, e.g., the data itself.

Looking to FIG. **9**, a magnetic tape **900** having an index partition **902** and a data partition **904** is illustrated according to one approach. As shown, data files and indexes are stored on the tape. The LTFS format allows for index information to be recorded in the index partition **902** at the beginning of tape **906**, as would be appreciated by one skilled in the art upon reading the present description.

As index information is updated, it preferably overwrites the previous version of the index information, thereby allowing the currently updated index information to be accessible at the beginning of tape in the index partition. According to the specific example illustrated in FIG. **9**, a most recent version of metadata Index 3 is recorded in the index partition **902** at the beginning of the tape **906**. Conversely, all three version of metadata Index 1, Index 2, Index 3 as well as data File A, File B, File C, File D are recorded in the data partition **904** of the tape. Although Index 1 and Index 2 are old (e.g., outdated) indexes, because information is written to tape by appending it to the end of the previously written data as described above, these old indexes Index 1, Index 2 remain stored on the tape **900** in the data partition **904** without being overwritten.

The metadata may be updated in the index partition **902** and/or the data partition **904** the same or differently depending on the desired approach. According to some approaches, the metadata of the index and/or data partitions **902**, **904** may be updated in response to the tape being unmounted, e.g., such that the index may be read quickly from the index partition when that tape is mounted again. The metadata is preferably also written in the data partition **904** so the tape may be mounted using the metadata recorded in the data partition **904**, e.g., as a backup option.

According to one example, which is no way intended to limit the invention, LTFS LE may be used to provide the functionality of writing an index in the data partition when a user explicitly instructs the system to do so, or at a time designated by a predetermined period which may be set by the user, e.g., such that data loss in the event of sudden power stoppage can be mitigated.

As mentioned above, difficulties are encountered when attempting to increase the number of concurrent channels in heads to enable increase in data rate per unit of tape speed, such as increase in crosstalk between writers, increase in writer coil resistance, difficulty in managing greater congestion in the wiring layers, higher operating temperature, etc. Various apparatuses and methods presented herein address difficulties encountered when attempting to increase the number of concurrent channels in heads to enable increase in data rate per unit of tape speed.

Various approaches described below include a new head design that is capable of reading and/or writing to magnetic media such as magnetic recording tape in multiple formats. For example, the head can write and/or read data in both legacy and advanced formats, and in doing so can enable full backward compatibility with legacy media types. This is an important criterion for users wishing to move to a new format yet having data stored on media in an older format.

The following description also presents solutions to the problem of designing and making a magnetic tape head which increases the data rate but is backward compatible with prior tape formats. Various approaches also advantageously allow such head to be built from two or more face-to-face modules, two or more of which are generally identical, and have a minimal set of transducers.

Various approaches are associated with a format for magnetic tape recording products and systems whereby data is read from and/or written to two data bands simultaneously. Such format addresses the need for a configuration that enables higher data rate by allowing more active transducer channels in use per wrap, but at the same time provides backward compatibility to at least a previous (legacy) generation having fewer active transducer channels in use per wrap.

Consider, for example, Linear Tape Open, 8^{th} generation (LTO-8), which is a 32 channel format that is backward compatible to LTO-5, which is a 16 channel format. LTO was created at the outset to accommodate both 8 and 16 channel formats, and has since moved to 32 channel formats, and thus enables a transition from 16 to 32 channels. Continuing with this example, transitioning from LTO-8 to a format using 64 channels and keeping backward compatibility means at least 32 of the transducers must align with the track layout specified by LTO-8. To transition to 64 transducers and stay within a single data band, the pitch between channels would need to be halved. Again, this creates a plethora of problems.

In some approaches described herein, a legacy transducer layout compatible with a legacy format is replicated one or more fold in the same gap of the same head module. Replicated arrays also align with data bands on the tape, thereby enabling reading and/or writing to data tracks in two data bands simultaneously. This effectively doubles the data rate, and avoids the aforementioned problems encountered when trying to squeeze twice the number of transducers into a single data band width.

FIGS. **10-16** depict an apparatus **1000**, in accordance with various approaches of the present invention. As an option, the present apparatus **1000** may be implemented in conjunction with features from any other approach listed herein, such as those described with reference to the other FIGS. Of course, however, such apparatus **1000** and others presented herein may be used in various applications and/or in permutations which may or may not be specifically described in the illustrative approaches listed herein. Further, the apparatus **1000** presented herein may be used in any desired environment.

Except as otherwise described herein the apparatus **1000** may be constructed via conventional techniques modified to create the new and novel structures described herein. Moreover, except as otherwise described herein the apparatus **1000** may operate using conventional techniques modified as described herein, and/or as would become apparent to one skilled in the art upon reading the present disclosure.

As shown in FIG. **10**, the apparatus **1000** includes a module **1002** having two arrays **1004**, **1006**, each array having a plurality of data transducers. The arrays **1004**, **1006** are aligned along a common axis **1008** extending between distal ends of the module **1002**. Each array aligns to a unique data band on the magnetic recording tape when in use.

Preferably, the arrays **1004**, **1006** are positioned in the same thin film gap of the module, which advantageously allows simultaneous fabrication of the transducers.

The data transducers in the arrays may be of any type. The data transducers in both arrays are preferably of the same type, e.g., all readers, all writers, piggybacked or merged reader/writer pairs, etc. Also preferably, the pitch between the transducers in each array is the same. Moreover, any number of transducers may be present in each array, e.g., 32, 33, 64, 65, 128, 129, etc.

Two (or more) outer servo readers **1010**, **1012** are positioned toward outer ends of the two arrays **1004**, **1006**. An inner servo reader **1014** is positioned between the two arrays **1004**, **1006**. The servo readers **1010**, **1012**, **1014** are positioned to each reside above a unique servo track on a magnetic recording tape.

In further approaches, multiple servo readers may be positioned together at any of the servo reader locations disclosed herein. For example, two or more servo readers may be present adjacent an array to enable use with various types of servo patterns, such as, for example, patterns having high density transitions, steeper angle transitions, etc. In one aspect, one of the servo readers in the group of servo readers may be a servo reader positioned in the legacy position, which corresponds to servo track centerlines on the tape. In another aspect, two servo readers in the group are centered about the legacy position.

As depicted in FIG. **10**, the inner servo reader **1014** is positioned along a centerline **1016** of the module, the centerline being positioned at about a center of the common axis **1008** and oriented along a tape travel direction **1018** relative to the module **1002**.

FIG. **11** depicts another configuration of the apparatus **1000**. As shown, the third servo reader **1014** and arrays **1004**, **1006** are offset from the centerline **1016** of the module **1002**. Any desired offset may be used in various approaches. An advantage of this configuration is that one of the arrays may be centered along the centerline **1016**, e.g., the midpoint of the array is centered between distal ends of the module, which in turn assists in using that array for operations according to a legacy format.

In use, when the transducers of both arrays **1004**, **1006** are reading or writing simultaneously, the outer servo readers **1010**, **1012** are used for track following in one approach. However, in other approaches the third servo reader **1014** and one or both outer servo readers are used for track following. Accordingly, any combination of servo readers may be used for track following. In general, the more servo readers being used, the more accurate the track following, at the cost of using more system resources. Any type of servo pattern and/or track following technique may be used, including conventional patterns and techniques.

When operating according to a legacy format where all data tracks simultaneously operated on are within a single data band, one of the arrays is selected for use. The third servo reader **1014** and the outer servo reader adjacent the selected array are used for track following.

FIG. **12** depicts use of the apparatus **1000** of FIG. **10** for reading a format where all data tracks simultaneously operated on in a given pass are within two adjacent data bands. For example, when the module **1002** is positioned at position A, the two leftmost data bands **1202**, **1204** of the magnetic recording tape **1200** are operated on simultaneously using the arrays **1004**, **1006**. Any type of reading or writing may be performed such as, for example, serpentine or nonserpentine shingled writing. As shown, each of the servo readers **1010**, **1012**, **1014** is positioned above a respective servo track **1210**. Any combination of the servo readers may be used for track following.

Once the data operation is completed in data bands **1202**, **1204**, the module **1002** may be moved to position B to position the arrays **1004**, **1006** above the rightmost data bands **1206**, **1208**, and the desired operation performed.

FIG. **13**A depicts use of the apparatus **1000** of FIG. **10** for reading a legacy format where all data tracks simultaneously operated on in a given pass are within a single data band of the magnetic recording tape **1200**. Operation is similar to that described with reference to FIG. **12**, except only one array **1006** is used at a time, and the module **1002** is moved to positions A-D to operate on each data band. Track following may be performed using servo readers **1012** and **1014**.

FIG. **13**B depicts use of the apparatus **1000** of FIG. **11** for reading a legacy format where all data tracks simultaneously operated on in a given pass are within a single data band of the magnetic recording tape **1200**. Operation is similar to that described with reference to FIG. **12**, except only one array **1004** or **1006** is used at a time, and the module **1002** is moved to position A or B to operate on each data band, and the array currently over the data band of interest is used. Track following may be performed using servo readers **1010**, **1012** and/or **1014**. This approach has the advantage of requiring less movement between data bands.

While FIGS. **10-13**B depict aspects where two arrays are present, other approaches include more than two arrays. For example, FIG. **14** depicts an approach with four arrays aligned along the common axis **1008**: the two arrays **1004**, **1006**, a third array **1402** of data transducers, and a fourth array **1404** of data transducers aligned along the common axis **1008**. Each array aligns with one of the data bands. A fourth servo reader **1406** is positioned toward an outer end of the third array **1402**. One outer servo reader **1010** is positioned between the third array **1402** and the two arrays **1004**, **1006**. A fifth servo reader **1408** is positioned toward an outer end of the fourth array **1404**.

One can envision further aspects where more than four arrays are present, such as 5, 6, 7, 8 arrays, and so on.

Additional approaches include arrays and flanking servo readers that are spaced apart to define a gap therebetween that is about as wide as a tape data band spacing. FIG. **15** illustrates an approach where the arrays **1004**, **1006** are spaced apart with no transducers therebetween, except optional inner servo readers **1502**. In this approach, the head needs to step only one data band to access an entire four-data band tape.

FIG. **16** depicts an approach having three arrays **1004**, **1006**, **1602** with a gap between two of the arrays along the common axis **1008**. Servo readers **1604** flank the third array **1602**. Preferably, no data transducers of the type in the arrays are present in the gap. The gap is about as wide as a data band of the magnetic recording tape.

While various positions of the transducer arrays are shown in FIGS. **10-16**, the arrays may be located in other positions relative to the centerline **1016** in various approaches. For example, positions of the arrays may be selected to ensure the tape does not extend beyond the edge of the module when in use.

In some aspects, the apparatus may include logic and/or a mechanism for adjusting the span of the module and/or the span of one or both arrays to accommodate tape and/or head expansion and/or contraction. Illustrative techniques include actively controlling tape tension, the use of heaters and/coolers to induce expansion/contraction of the module, piezo actuation of the module, tilting the module, etc.

As noted above with reference to FIG. **1**A, the apparatus **1000** may include a drive mechanism for passing a magnetic medium over the module and a controller electrically coupled to the module.

In one mode of use, the controller is configured to select one of the arrays according to a legacy mode of operation, perform track following using the servo readers adjacent the selected array, and transduce data in a single data band using only the selected array.

In another mode of use, the controller is configured to simultaneously transduce data on two data bands of the magnetic recording tape, and perform track following using at least two outer servo readers positioned outside the arrays.

In yet another mode of use, the controller is configured to simultaneously transduce data on two data bands of the magnetic recording tape, and perform track following using at least the servo reader positioned between arrays.

In any approach, the outer servo readers may be used for at least skew following.

Now referring to FIG. **17**, a flowchart of a method **1700** is shown according to one approach. The method **1700** may be performed in accordance with the present invention in any of the environments depicted in FIGS. **1-16**, among others, in various approaches. Of course, more or less operations than those specifically described in FIG. **17** may be included in method **1700**, as would be understood by one of skill in the art upon reading the present descriptions.

Each of the steps of the method **1700** may be performed by any suitable component of the operating environment. For example, in various approaches, the method **1700** may be partially or entirely performed by a tape drive or some other device having one or more processors therein. The processor, e.g., processing circuit(s), chip(s), and/or module (s) implemented in hardware and/or software, and preferably having at least one hardware component may be utilized in any device to perform one or more steps of the method **1700**. Illustrative processors include, but are not limited to, a central processing unit (CPU), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), etc., combinations thereof, or any other suitable computing device known in the art.

As shown in FIG. **17**, method **1700** may initiate with operation **1702**, where a magnetic recording tape having a plurality of data bands is passed over a module according to any approach described herein. Preferred approaches use a version of the module depicted in FIGS. **10-16**. Operation **1704** includes simultaneously transducing data on at least two of the data bands using the data transducers of the arrays, i.e., reading and/or writing.

In one aspect, one of the arrays may be selected according to a legacy mode of operation. Track following is performed using the servo readers adjacent the selected array. Data is transduced using only the selected array. See, e.g., FIGS. **13**A-**13**B.

Various additional operations may be performed, according to various aspects. For example, tape tension may be adjusted, e.g., tension may be used to adjust the width of the tape to help maintain registration between the transducers and the data tracks on tape. The effects of tensioning scale uniformly across the tape, making this approach very useful.

In another approach, the tilt of the arrays relative to longitudinal axes of the data bands may be adjusted to alter the pitch of the transducers as presented to the tape.

Known tape drive operations of any type may also be performed.

The present invention may be a system, a method, and/or a computer program product at any possible technical detail level of integration. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals per se, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, configuration data for integrated circuitry, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++, or the like, and procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

These computer readable program instructions may be provided to a processor of a computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the blocks may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be accomplished as one step, executed concurrently, substantially concurrently, in a partially or wholly temporally overlapping manner, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

Moreover, a system according to various embodiments may include a processor and logic integrated with and/or executable by the processor, the logic being configured to perform one or more of the process steps recited herein. By integrated with, what is meant is that the processor has logic embedded therewith as hardware logic, such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), etc. By executable by the processor, what is meant is that the logic is hardware logic; software logic such as firmware, part of an operating system, part of an application program; etc., or some combination of hardware and software logic that is accessible by the processor and configured to cause the processor to perform some functionality upon execution by the processor. Software logic may be stored on local and/or remote memory of any memory type, as known in the art. Any processor known in the art may be used, such as a software processor module and/or a hardware processor such as an ASIC, a FPGA, a central processing unit (CPU), an integrated circuit (IC), etc.

It will be clear that the various features of the foregoing systems and/or methodologies may be combined in any way, creating a plurality of combinations from the descriptions presented above.

It will be further appreciated that embodiments of the present invention may be provided in the form of a service deployed on behalf of a customer.

The inventive concepts disclosed herein have been presented by way of example to illustrate the myriad features thereof in a plurality of illustrative scenarios, embodiments, and/or implementations. It should be appreciated that the concepts generally disclosed are to be considered as modular, and may be implemented in any combination, permutation, or synthesis thereof. In addition, any modification, alteration, or equivalent of the presently disclosed features, functions, and concepts that would be appreciated by a person having ordinary skill in the art upon reading the instant descriptions should also be considered within the scope of this disclosure.

The descriptions of the various embodiments of the present invention have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

What is claimed is:

1. A method, comprising:

passing a magnetic recording tape having a plurality of data bands over a module having:

two arrays of data transducers aligned along a common axis extending between distal ends of the module, each array being positioned over a unique data band, wherein the pitch between the transducers in both arrays is the same,

outer servo readers positioned toward outer ends of the two arrays, and

at least one inner servo reader positioned between the arrays, wherein the inner and outer servo readers are positioned to each reside above a respective unique servo track on the, wherein the arrays are separated only by the at least one inner servo reader; and

simultaneously transducing data on the two data bands using the data transducers.

2. A method as recited in claim **1**, wherein the at least one inner servo reader is positioned along a centerline of the module, the centerline being positioned at about a center of the common axis and oriented along a tape travel direction.

3. A method as recited in claim **1**, wherein the at least one inner servo reader is offset from a centerline of the module, the centerline being positioned at about a center of the common axis and oriented along a tape travel direction.

4. A method as recited in claim **1**, wherein the module includes a third array of data transducers aligned along the common axis, and a servo reader positioned toward an outer end of the third array, wherein one of the outer servo readers is positioned between the third array and the two arrays.

5. A method as recited in claim **1**, comprising switching to a legacy mode of operation, selecting one of the arrays according to the legacy mode of operation, performing track following using the servo readers adjacent the selected array, and transducing data using only the selected array.

6. A method as recited in claim **1**, comprising performing track following using at least the outer servo readers while transducing the data.

7. A method as recited in claim **1**, comprising performing track following using at least the at least one inner servo reader while transducing the data.

8. A method as recited in claim **1**, comprising adjusting a parameter selected from the group consisting of: tape tension, and tilt of the arrays relative to longitudinal axes of the data bands.

9. A method as recited in claim **1**, wherein the two arrays are positioned on the module to operate on two data bands of the magnetic recording tape that are directly adjacent the unique servo track below which the at least one inner servo reader is positioned to reside.

10. A method as recited in claim **1**, wherein the at least one inner servo reader incudes a second inner servo reader.

11. A method as recited in claim **1**, comprising at least a second outer servo reader positioned together with each outer servo reader.

12. An apparatus, comprising:

a module having:

two arrays of data transducers aligned along a common axis extending between distal ends of the module, each array being located on the module for positioning over a unique data band, wherein the pitch between the transducers in both arrays is the same,

outer servo readers positioned toward outer ends of the two arrays, and

an inner servo reader positioned between the arrays, wherein the inner and outer servo readers are positioned to each reside above a respective unique servo track on the, wherein the arrays are separated only by the inner servo reader; and

a controller configured to:

cause the magnetic recording tape having a plurality of data bands to pass over the module, and

simultaneously transduce data on the two data bands using the data transducers in a first mode of operation.

13. An apparatus as recited in claim **12**, wherein the inner servo reader is positioned along a centerline of the module, the centerline being positioned at about a center of the common axis and oriented along a tape travel direction.

14. An apparatus as recited in claim **12**, wherein the inner servo reader is offset from a centerline of the module, the centerline being positioned at about a center of the common axis and oriented along a tape travel direction.

15. An apparatus as recited in claim **12**, wherein the controller is also configured to operate in a legacy mode of operation, in which the controller is operable to select one of the arrays according to a legacy mode of operation, perform track following using the inner and outer servo readers adjacent the selected array, and transduce data using only the selected array.

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